80 & 90

NORTHERN SKYE

7770747

GEOLOGICAL SURVEY OF GREAT BRITAIN

THE GEOLOGY OF NORTHERN SKYE

EDINBURGH
HER MAJESTY'S STATIONERY OFFICE

oxford polytechnic
Library
554·1182 AND
49753

OXFORD
POLYTECHNIC
LIBRARY

16. FEB 1998

09. OCT. 2000

WITHDRAWN

WITHDRAWN

19. OCT. 1984

2. JUL. 1987

~~3. MAY 1988~~

8. MAY 1992

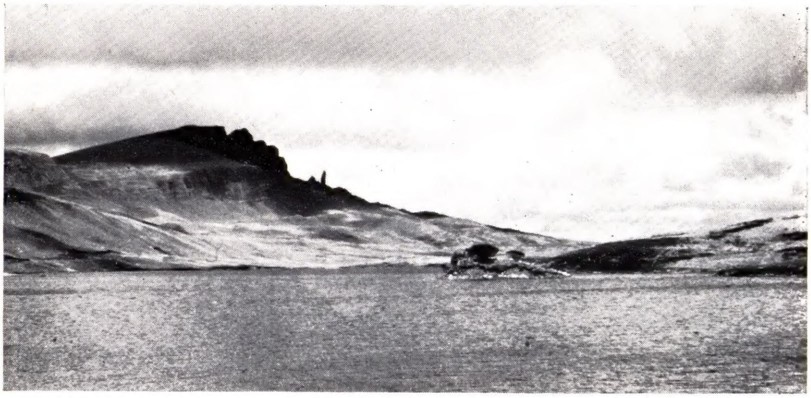
28. APR 1995

28. APR. 1995

16. FEB. 1998

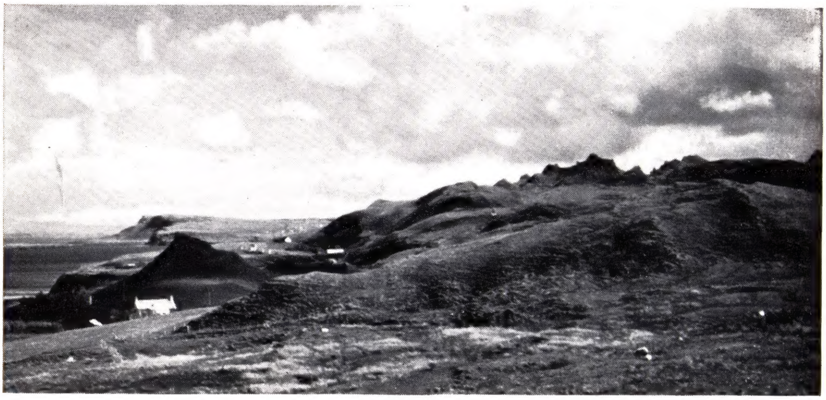
TELEPEN

0004975309



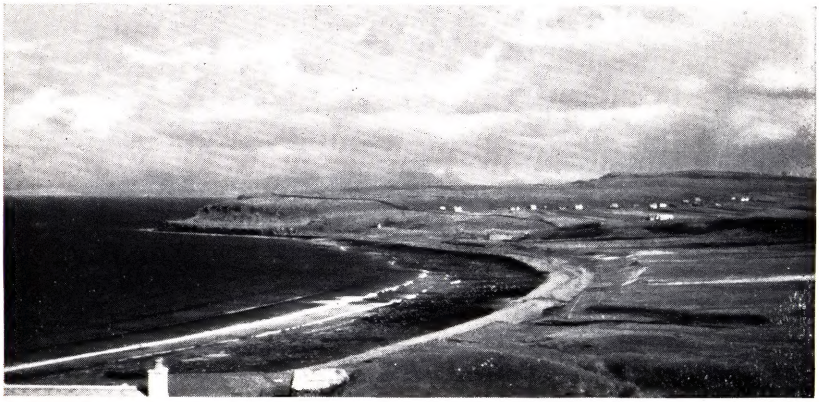
(MN20706)

A. THE STORR FROM THE SOUTH; PART OF THE TROTTERNISH LAVA-SCARP



(MN20704)

B. LANDSLIP TOPOGRAPHY SOUTH OF FLODIGARRY HOTEL



(MN20705)

C. STAFFIN BAY FROM THE NORTH

STOCKTAKING 1977

MEMOIRS OF THE GEOLOGICAL SURVEY
SCOTLAND

The Geology of Northern Skye

EXPLANATION OF THE PORTREE (80) AND PARTS OF THE RUBHA HUNISH (90), APPLECROSS (81) AND GAIRLOCH (91) SHEETS

By

F. W. ANDERSON, D.Sc., F.I.Biol., F.R.S.E.

and

K. C. DUNHAM, D.Sc., S.D., M.I.M.M., F.R.S.

EDINBURGH: HER MAJESTY'S STATIONERY OFFICE
1966

© *Crown Copyright* 1966

PREFACE

THE AREA described in the present memoir was surveyed on the six-inch to the mile scale by the late J. K. Allan, the late D. Haldane, Mr J. Knox, Mr. T. R. M. Lawrie, Dr. T. Robertson with the late G. V. Wilson as District Geologist between the years 1934–39. Certain marginal areas, partly surveyed in 1894–98 by A. Harker and H.B. Woodward, were re-examined by Messrs. F. W. Anderson, J. Knox and T. R. M. Lawrie. The Jurassic coastal areas were visited by C. B. Wedd in 1912 and in 1913 by G. W. Lee, who made certain modifications in the earlier mapping. During 1936–38 and 1947 Dr. F. W. Anderson made a detailed examination of the Jurassic and Tertiary sediments and remapped some areas. The late Dr. L. F. Spath contributed greatly by identifying all the ammonities and the late Sir Albert Seward and the late W. N. Edwards reported on the Tertiary plants. The remaining fossils have been identified by Dr. F. W. Anderson. The petrographical investigation of the lavas and minor intrusions begun by Dr. K. C. Dunham during his period as Chief Petrographer was continued by him after he resigned to become Professor of Geology at Durham.

The maps have been compiled and seen through the press by Dr. Anderson; the composite one-inch map comprising the Portree (80) Sheet, the Skye portion of the Rubha Hunish (90) Sheet and part of the Applecross (81) and Gairloch (91) sheets was published both in solid and drift editions in 1964. Dr. Anderson has also written the memoir except for chapters VII, IX, and X, dealing with the petrography, which are the work of Professor Dunham. The memoir has been edited by Dr. G. H. Mitchell.

C. J. STUBBLEFIELD
Director.

GEOLOGICAL SURVEY OFFICE
EXHIBITION ROAD,
SOUTH KENSINGTON,
LONDON, S.W.7.
5th May, 1965.

CONTENTS

(References are listed at the end of each chapter)

PAGE

PREFACE BY THE DIRECTOR iii

LIST OF ILLUSTRATIONS vi

EXPLANATION OF PLATES vii

LIST OF SIX-INCH MAPS viii

CHAPTER I INTRODUCTION 1

Area and Physical Features, 1; Summary of Geology, 4.

CHAPTER II JURASSIC: General, Lias and Inferior Oolite 7

General Account, 7; Middle Lias, 9; Upper Lias, 10; Inferior Oolite, 12.

CHAPTER III JURASSIC: Great Estuarine Series 18

General description, 18; Oil-Shale, 21; White Sandstone, 21; '*Estheria*' Shales, 23; Concretionary Sandstones, 26; Lower '*Ostrea*' Beds, 36; Ostracod Limestones, 43; Mottled Clays, 48; Upper '*Ostrea*' Beds, 51; Belemnite Sands, 53.

CHAPTER IV JURASSIC: Oxford Clay to Kimmeridge Clay 56

Oxford Clay, 57; Corallian, 65; Kimmeridge Clay, 70.

CHAPTER V TERTIARY SEDIMENTS 73

Palagonite Tuffs, 73; Interbasaltic Sediments, 77.

CHAPTER VI TERTIARY LAVAS 79

General Account, 79; Beinn Edra Group, 81; Ramascaig Group, 86; Beinn Totaig Group, 88; Bracadale Group, 90; Osdale Group, 90; Magmatic Sources for the Lava Suite, 90.

CHAPTER VII PETROGRAPHY OF THE VOLCANIC ROCKS 93

History of Research, 93; Palagonite Tuffs, 95; Tholeiitic Pillow Lavas, 98; Main Lava Series, 100; Hebridean type, 104; Vaternish Hebridean type, 111; Feldspar-phyric Olivine-basalt, 115; Mugearite, 116; Big-feldspar Mugearite and Mugearite-basalt, 120; Trachyte, 122.

CHAPTER VIII INTRUSIVE IGNEOUS ROCKS.. 125

Tertiary Sills, 125; Dykes, 132; Trachyte, 133; Mugearite, 133; Dolerite, 134; Picritic Dolerite, 135; Gabbro and Allivalite, 136; Regional Dolerite dykes, 137; Multiple Intrusions, 137; Age relations of dykes, 138; Inclined Sheets, 139; Vents and Agglomerates, 139.

CHAPTER IX PETROGRAPHY OF THE MINOR INTRUSIONS 140

History of Research, 140; Petrography of the Sills, 141; Olivine-dolerite, 141; Picrodolerite, 143; Crinanitic and Teschenitic Dolerites, 146; Pegmatitic Dolerite, 147; Chemical Composition, 148; Petrography of the Dykes, 149; Normal Olivine-dolerite and basalt, 150; Crinanitic Variants, 151; Picritic Dolerites—Picrites, 151; Mugearite, 152; Variolite, 152; Leidleite, 153; Trachyte, 153; Feldspar-phyric Dolerite and Basalt, 153; Allivalite, Olivine-eucrite, Gabbro, 155; Tholeiite, 157; Porphyritic Tholeiites, 158.

CHAPTER X IGNEOUS PETROLOGY 160

The initial eruption in North Skye, 160; The Alkaline Olivine-basalt Suite, 160; Allivalitic and Feldspar-phyric Rocks, 170; Summary, 170.

CHAPTER XI TECTONIC HISTORY 172

Pre-Triassic, 172; Post-Triassic–Pre-Tertiary, 173; Tertiary Movements, 175.

CHAPTER XII QUATERNARY 177

Glaciation, 177; Retreat of Highland Ice, 181; Late-Glacial Re-advance, 182; Valley Glacier Retreat stages, 184; Glacial Erosion, 184; Glacial Deposits, 185; Erratic Boulders, 185; Moraines, 185; Sands and Gravels, 185; Raised Beaches, 186; Landslip, 186; Rockfalls and Scree, 194; Diatomite, 195; Alluvium, 195; Blown Sand, 196; Olivine Sand, 196; Musical Sands, 196; Nullipore 'Sands' 196.

CHAPTER XIII ECONOMIC GEOLOGY 198

Ironstone, 198; Jet, 198; Oil-Shale, 198; Lignite, 199; Peat, 199; Diatomite, 199; Road Metal, 201; Limestone, 201; Shell Sand, 201; Honestone, 201; Water, 202.

APPENDIX LIST OF GEOLOGICAL SURVEY PHOTOGRAPHS 203

INDEX 205

ILLUSTRATIONS

TEXT FIGURES

PAGE

FIG. 1. Sketch-map showing distribution of main groups of rocks in Northern Skye 2

FIG. 2. Generalized vertical section of sedimentary and volcanic rocks exposed in Northern Skye 5

FIG. 3. Section in sea-cliff at Fiurnean, 4 miles N.N.E. of Portree .. 14

FIG. 4. Sections showing the sequence of strata in the Concretionary Sandstones, Lower '*Ostrea*' Beds, Ostracod Limestones, Mottled Clays, Upper '*Ostrea*' Beds, Oxford Clay, Corallian and Kimmeridge Clay 20

FIG. 5. Section in sea-cliff on north side of Portree Bay 22

FIG. 6. Section in sea-cliff between Upper Tote and Inver Tote 24

FIG. 7. Section in sea-cliff between Drum Dearg and Loch Mealt fall .. 30

FIG. 8. Map of Jurassic strata in Staffin Bay, coast east of Digg 49

FIG. 9. Map of Jurassic strata in Staffin Bay, coast east of Loch Leum nam Bradh 58

FIG. 10. Map of Jurassic strata in Staffin Bay, coast east of Loch Langaig 60

FIG. 11. Map of Jurassic strata in Staffin Bay, coast south-east of Flodigarry Hotel 64

FIG. 12. Correlation of the Jurassic strata exposed in Staffin Bay 68

FIG. 13. Sketch-map showing the outcrops of the main lava-groups and section showing their mutual relationships 82

FIG. 14. Section showing the behaviour of part of the Tertiary sill-complex at Eist 130

FIG. 15. Modes of a suite of specimens collected at intervals in the central chimney cutting the Meall Tuath upper sill, Rubha Hunish .. 144

FIG. 16. Plot of compositions of normative feldspars in Hebridean lavas and sills 161

FIG. 17. Variation diagram for the Alkaline Olivine-basalt lavas and minor intrusions 162

FIG. 18. Plots of iron oxide-magnesia ratio and iron oxide-content against silica 168

FIG. 19. Sketch-map showing movement of ice and other glacial features in Skye 178

FIG. 20. Glacial retreat stages in Trotternish, Isle of Skye 180

FIG. 21. The Bracadale–Edinbain late-Glacial lake system at the 550-ft retreat stage 183

FIG. 22. Section of the Quirang Landslip 188

FIG. 23. Section of The Storr Landslip 191

PLATES

Plate I. A. The Storr from the south; part of the Trotternish lava-scarp.

Landslipped lavas and Jurassic sediments form the ground to the right of the escarpment. In the foreground a glacially eroded hollow in Jurassic sediments is occupied by the two lochs Fada and Leathan, which supply water for the Bearreraig Hydro-electric Station. (MN20706)

B. Landslip topography south of Flodigarry Hotel.

In the foreground slipped masses of Tertiary lava and Jurassic sediments. In the distance the headland of Rubha Garbhaig is of Tertiary dolerite sills in Jurassic sediments. (MN20704)

C. Staffin Bay from the north.

On the foreshore are upper Jurassic sediments. In the middle distance Staffin Point (An Corran) is formed by two dolerite sills with Jurassic sediments between them. Behind the storm beach the 25-ft and 50-ft beach flats are well seen and correspond with the rock notches seen in An Corran. (MN20705) *Frontispiece*

FACING PAGE

Plate II. A. Bearreraig, six miles north-north-east of Portree.

Inferior Oolite sandstone giving rise to waterfall. (C2241)

B. Lyndale Point, 100 yd from shore, 1530 yd north-north-west of Lynedale House.

Dolerite dyke showing columnar jointing. (C3919) 15

Plate III. A. Bearreraig Bay, 6½ miles north-north-east of Portree.

Columnar sill of dolerite overlying Inferior Oolite. (C2244)

B. Coast, south of Mealt Waterfall, looking north from Valtos.

Great Estuarine Series with intruded sills of dolerite. (C3898) 126

Plate IV. The Quirang, looking north-east from Uig road.

Escarpment of Tertiary lavas with extensive area of landslipped masses of Tertiary volcanic material. Staffin is on the extreme right. (C3899–3900) 190

LIST OF SIX-INCH MAPS

Geological six-inch maps included wholly or in part in the area covered by the one-inch map of Northern Skye are listed below with initials of the surveyors and dates of survey. The surveyors were J. K. Allan, F. W. Anderson, D. Haldane, J. Knox, T. R. M. Lawrie, T. Robertson and G. V. Wilson.

The maps all belong to the County Series. Maps on the National Grid were not available at the time of preparation. The completed maps are deposited at the Geological Survey Office, 19 Grange Terrace, Edinburgh, 9, where they are available for public reference.

Inverness-shire

1	N.E.	Fladda-chuain	D.H.	1934
2	S.W.	Rubha Hunish	D.H., F.W.A.	1935–36
3	N.E.	An t'Iasgair	D.H.	1934
3	S.E.	Kilmuir	D.H., F.W.A.	1934–36
4	N.W.	Kilmaluag	D.H., F.W.A.	1935–36
4	N.E.	Bagh nan Gunnaichean	D.H., F.W.A.	1934–36
4	S.W.	Heribusta	D.H., F.W.A.	1934–36
4	S.E.	Flodigarry	D.H., F.W.A.	1934–36
5	N.W.	Vaternish Point	D.H.	1935
5	S.W.	Unish	D.H.	1935
5	S.E.	Eilean Iosal	D.H.	1935
6	N.E.	Balgown	D.H., F.W.A.	1935–36
6	S.W.	Sgeir a'Chapuill	D.H.	1935
6	S.E.	Totscore	J.K., F.W.A.	1934–36
7	N.W.	Suidh' a'Mhinn	D.H.	1934
7	N.E.	Stenscholl	D.H., F.W.A.	1934–36
7	S.W.	Ben Gorm	J.K.	1934
7	S.E.	Loch Dubhar-Sgoth	J.K.	1934
8	N.W.	Rubha Garbhaig	D.H., F.W.A.	1934–36
8	S.W.	Loch Mealt	J.K., F.W.A.	1934–36
9	N.W.	Trumpan	D.H., F.W.A.	1935–37
9	N.E.	Geary	D.H.	1935
9	S.W.	Ardmore Point	D.H.	1935
9	S.E.	Score Horan	D.H.	1935
10	N.W.	South Ascrib	D.H.	1935
10	N.E.	Earlish	J.K.	1934–35
10	S.W.	Creagan Glasa	D.H.	1935
10	S.E.	Lyndale Point	D.H., J.K.	1935–36
11	N.W.	Beinn Fhuar	J.K.	1934–35
11	N.E.	Beinn Edra	J.K.	1934–35
11	S.E.	Creag a'Lain	J.K.	1935–37
12	N.W.	Lealt	J.K., F.W.A.	1934–37
12	S.W.	Creag Langall	J.K., F.W.A.	1934–37
14	N.E.	Dunvegan Head	D.H.	1939
14	S.E.	Boreraig	J.K.A., D.H.	1938–39
15	N.W.	Lovaig Bay	D.H.	1935–36
15	N.E.	Loch Bay	D.H., F.W.A.	1935–37
15	S.W.	Beinn Mhic Uilleim	D.H.	1936–39
15	S.E.	Bay River	D.H.	1936
16	N.W.	Greshornish	D.H.	1935–36
16	N.E.	Kildonan	D.H., J.K	1936–38
16	S.E.	Flashader	D.H., J.K.	1938–39
17	N.W.	Kingsburgh	J.K.	1936
17	N.E.	Hartaval	J.K.	1936

17	S.W.	Eyre	J.K., G.V.W.	1936–37
17	S.E.	Glenhaultin	J.K., G.V.W.	1936–37
18	N.W.	The Storr	J.K., F.W.A.	1935–37
18	S.W.	Loch Leathan	F.W.A., G.V.W.	1935–37
20	N.W.	Oisgill Bay	J.K.A., F.W.A.	1938
20	N.E.	Holmisdal	J.K.A.	1938
20	S.W.	Eist	J.K.A., F.W.A.	1938
20	S.E.	Beinn nan Corrafidheag	J.K.A.	1938
21	N.W.	Colbost	J.K.A., D.H.	1935–36
21	N.E.	Dunvegan	J.K.A., D.H.	1935–36
21	S.W.	Skinidin	J.K.A., D.H.	1935, 1938
21	S.E.	Kilmuir	J.K.A., D.H.	1935–37
22	N.W.	Strone Geers	D.H.	1936
22	N.E.	Ben Uigshader	D.H., J.K.	1938–39
22	S.E.	Loch Ravag	D.H., J.K.	1937–38
23	N.W.	Tote	J.K., G.V.W.	1935, 1938
23	N.E.	Borve	G.V.W.	1935–36
23	S.W.	Beinn a'Ghlinne Bhig	J.K., G.V.W.	1935, 1938
23	S.E.	Glengrasco and N.W. Portree	G.V.W.	1935
24	N.W.	Loch Fada and Lon nam Breac	F.W.A., G.V.W.	1935–36, 1939
24	S.W.	Torvaig and N.W. Portree	F.W.A., T.R.M.L., G.V.W.	1935–36, 1939
26	N.E.	Ramasaig	J.K.A., D.H.	1938
26	S.E.	Lorgill Bay	D.H.	1938
27	N.W.	Healaval Bheag	D.H.	1938
27	N.E.	Orbost	J.K.A., D.H.	1935, 1937–38
27	S.W.	Glen Ollisdal	D.H.	1938
27	S.E.	Harlosh Point	D.H.	1937–38
28	N.W.	Loch Caroy	D.H., T.R.	1935, 1937
28	N.E.	Ben Scudaig	D.H., J.K., T.R.	1935, 1937–38
28	S.W.	Colbost	D.H., T.R.	1935, 1937
28	S.E.	Bracadale	T.R.	1935
29	N.W.	Am Maol	J.K., G.V.W.	1935–37, 1939
29	N.E.	S.W. Portree and Beinn na Greine	J.K., G.V.W.	1935–37
29	S.W.	Loch Duagrich	J.K., T.R.	1935, 1937, 1939
29	S.E.	Mugeary	J.K., G.V.W.	1935, 1937
30	N.W.	Camas Ban and S.E. Portree	T.R.M.L., G.V.W., F.W.A.	1936, 1939
30	S.W.	Creag a'Chait	T.R.M.L., G.V.W., F.W.A.	1935, 1939
32A		Mi-bogha Mor	D.H.	1937
32	N.W.	Flossnan	D.H.	1937–38
32	N.E.	Idrigill Point	D.H.	1938
33	N.W.	Oronsay and Wiay	D.H., T.R.M.L.	1935, 1937, 1939
33	N.E.	Sumardale	T.R.M.L., T.R.	1935, 1939
34	N.W.	Glen Vidigill	J.K.	1939
34	N.E.	Meall an Fhuarain	J.K., T.R.M.L.	1939
35	N.W.	Beinn nan Capull	T.R.M.L., F.W.A.	1938–39
35	N.E.	Dunan an Aisilidh	T.R.M.L., F.W.A.	1938–39

Chapter 1

INTRODUCTION

Area and Physical Features

Memoirs dealing with the geology of the southern half of Skye have been available for many years. That by A. Harker (1904) is a classic work on the Tertiary igneous rocks of the Cuillin Hills and adjacent areas. Later a memoir (Peach and others 1910) dealt with the Strath between Broadford and Torran and the peninsulas of Strathaird and Sleat. A description of the Mesozoic rocks of the east coast of nothern Skye was included in a memoir by G. W. Lee (1920) on Applecross and Raasay.

The present memoir deals with the remaining part of Skye, i.e. that covered by one-inch Portree (80) and Rubha Hunish (90) sheets, whilst for the sake of completeness the coastal strip which appears marginally on one-inch Applecross (81) and Gairloch (91) sheets has been included. The small portion of Harris around Grosebay in the Outer Hebrides, an area of six square miles, has been omitted from both map and memoir because the rocks there exposed have no connexion with those appearing in N. Skye.

The area covered by the present memoir is about 670 square miles, of which about one third is sea. Topographically as well as geologically Skye falls into three very different subdivisions. The peninsula of Sleat is built exclusively of the older rocks, Lewisian to Cambrian in age, with a mature, heavily glaciated topography; the central area is one of violent contrasts including the jagged peaks of the Cuillins and the rounded Red Hills, both carved out of Tertiary plutonic rocks, whilst to the south and east are low-lying areas of Jurassic rocks. N. Skye on the other hand, together with the Strathaird peninsula, is built up of a great thickness of lava flows, Tertiary in age, resting on a platform of Jurassic rocks into which have been intruded numerous dolerite sills (Fig. 1). The topography is rugged, rocky, and in places spectacular, though there are large areas of hummocky, peat-covered ground.

The coast is deeply indented, in fact no part of N. Skye is more than five miles from the sea, and the coastal scenery is impressive. On the east coast the Jurassic rocks and the included sills form step-like cliffs which, near Portree, rise more than 1200 ft above sea-level. The steep cliffs formed by the lavas on the west are even more spectacular, for example Biod Ban in Oisgill Bay rises almost vertically to 641 ft and Biod an Athair near Dunvegan Head is over 1000 ft high.

Topographically, N. Skye is in the form of three northward projecting peninsulas; the western one, Duirinish, is almost an island, whilst the central and eastern ones, Vaternish and Trotternish, project from a central area lying between Portree and Dunvegan.

This central area, except for a group of hills to the south-west of Portree, nowhere exceeds 1000 ft in height and is typically an area of complex drainage

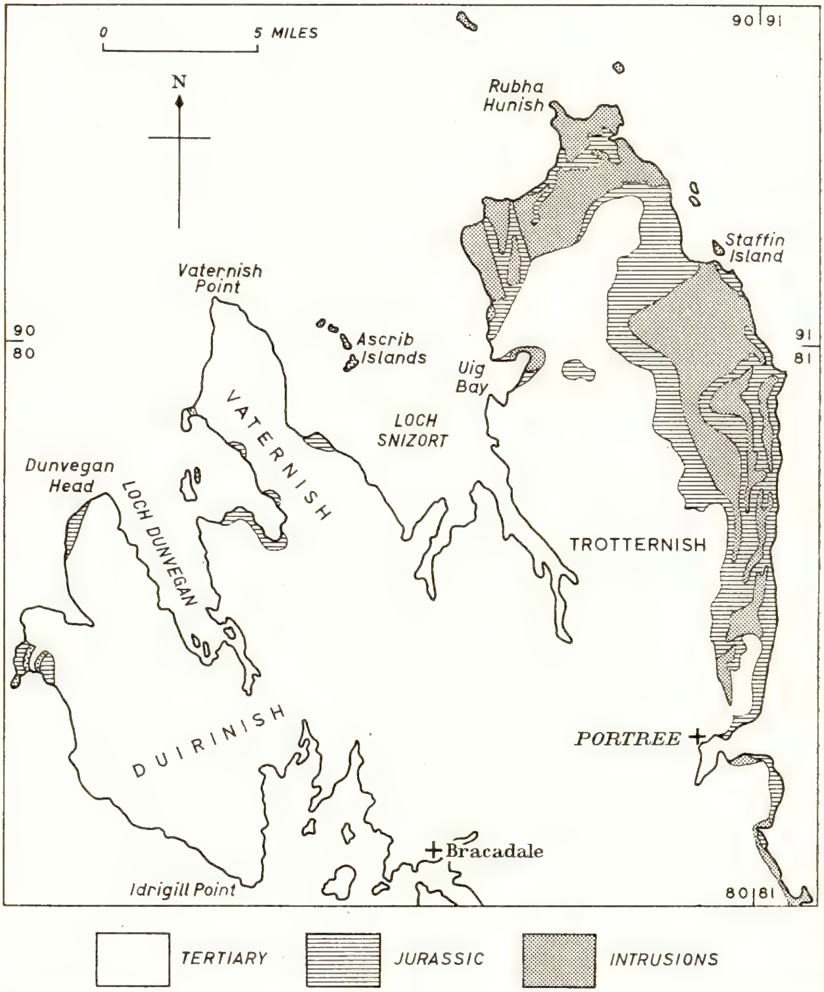


FIG. 1. *Sketch map showing distribution of main groups of rocks in Northern Skye. Figures indicate margins of one-inch sheets*

with many small lochans. Within it lie almost all the more recent of the lava-flows. It is cut off from the Trotternish peninsula by a low-lying strath which runs north-westwards from Portree and is continued by Loch Snizort Beag. Loch Greshornish, the valleys of the Red Burn and the Caroy River, and Loch Bracadale separate it from the Vaternish peninsula and Duirinish.

The Trotternish peninsula is traversed throughout most of its length by the high ridge of the lava escarpment. From Portree this ridge rises to 2360 ft at The Storr, then gradually descends to Meall nan Suireamach (1779 ft) at its northern end. At irregular intervals its edge has been scooped out by glacial action and landslip into scallops e.g. Bealach a'Chairn, Bealach Hartaval, Bealach na Leacaich, Bealach Chaiplin etc., leaving peaks between like The Storr, Creag a'Lain and Beinn Edra. To the east of the escarpment along its whole length lies the most extensive landslip in Britain. Great columns of lava have collapsed and slipped to form a confused mass of tumbled rock which extends in a series of jagged ridges some thousands of feet from the scarp, and at its northern end, the Quirang, to the sea. From the outer margin of the landslip the ground is more or less coincident with the dip-slope of the underlying Jurassic sediments to the sea-cliff.

Tertiary sills within these sediments often give rise to spectacular scenery like the Kilt Rock, Staffin, where columnar dolerite forms the upper half of the sea-cliff and Rubha Hunish where the sill forms a bastion 300 ft high. Along this east coast the rivers descend to sea-level in steep-sided gorges frequently displaying impressive waterfalls; the finest, those in the Bearreraig River which drains Loch Leathan and Loch Fada, have now been deprived of water by the Hydro-electric Scheme, but those in the R. Lealt farther north still function.

An unusual fall over a vertical cliff and dropping 170 ft directly into the sea is that draining Loch Mealt, the margin of which reaches almost to the cliff-edge.

In marked contrast to the eastern side, the western slopes of the Trotternish ridge are gentle and largely follow the low westward dip of the lavas. The slope is dissected by consequent streams which originate in glaciated corries and then flow through wide valleys into Loch Snizort. In one place, Glen Uig, the River Conon has cut through the lavas to expose in an amphitheatre the Jurassic sediments below.

The Vaternish peninsula also has a central ridge of lavas but it is mostly below 1000 ft in height and the base of the lavas is either just above or just below sea-level so that landslip topography is only developed in one or two places such as that at Score Horan on the east coast and on the northern and eastern slopes of Beinn Bhreac.

In Duirinish the lavas are lying almost flat or with a slight tilt to the east. The base emerges above sea-level in the west from Moonen Bay to Oisgill Bay, and there is landslipping at Waterstein Head.

The two best known peaks in Duirinish are Macleod's Tables, Healaval Mhor 1538 ft, and Healaval Bheag 1601 ft, both flat topped hills showing the characteristic step-like topography produced by the weathering of flat-lying lava-flows.

OXFORD POLYTECHNIC LIBRARY

SUMMARY OF GEOLOGY

Quaternary	
Holocene	Freshwater and Marine alluvium Peat, Diatomite Landslips, Rock fall; Scree
Pleistocene	Moraine Sand and gravel Boulder Clay
Tertiary	
Igneous	Minor intrusions, sills and dykes Lavas, basalts, mugearites, trachytes Tuffs, agglomerates, breccias
Sedimentary	Sandstones and shales Palagonite tuffs
	Unconformity
Jurassic	Kimmeridge Clay Corallian Clay Oxford Clay Great Estuarine Series Inferior Oolite Upper Lias shales Middle Lias sandstones

The oldest rocks exposed in Northern Skye are of Liassic age and these are only seen at intervals between Camastianavaig and Holm Island on the east coast. The Inferior Oolite, again only seen in coastal exposures, forms precipitous cliffs from Camastianavaig to Upper Tote. The sediments belonging to the Great Estuarine Series underlie the Tertiary lavas over the greater part of the area. They are best seen in Trotternish where they form the ground between the lava scarp and the east and north and north-west coasts, including the sea-cliff from Inver Tote to Staffin, and from Flodigarry to Uig Bay. Elsewhere they lie largely below sea-level and are only sporadically exposed by minor folds as in Loch Bay and in the extreme west between Moonen and Oisgill bays. The Oxford, Corallian and Kimmeridge clays are only found in Staffin Bay and in the Uig area (Fig. 2).

After the close of the Jurassic Period these sediments were folded into a gentle syncline with a slight northerly pitch to its north-north-east axis. Later the syncline was eroded apparently to base-level, for the Tertiary lavas were seemingly extruded over a peneplane with only the smallest irregularities on its surface.

Tertiary volcanic activity began, perhaps in the Eocene (but see p. 79) with explosive violence and a considerable thickness of tuffs was laid down in water over the whole area. At this time there was virtually no extrusion of lava but later, fissures developed from which welled vast quantities of predominantly basic lava covering the whole area to a thickness of probably not less than 4000 ft.

Pauses in this activity were sometimes long enough for vegetation to develop and the remains of plants are found in some places preserved in a few feet of sediments.

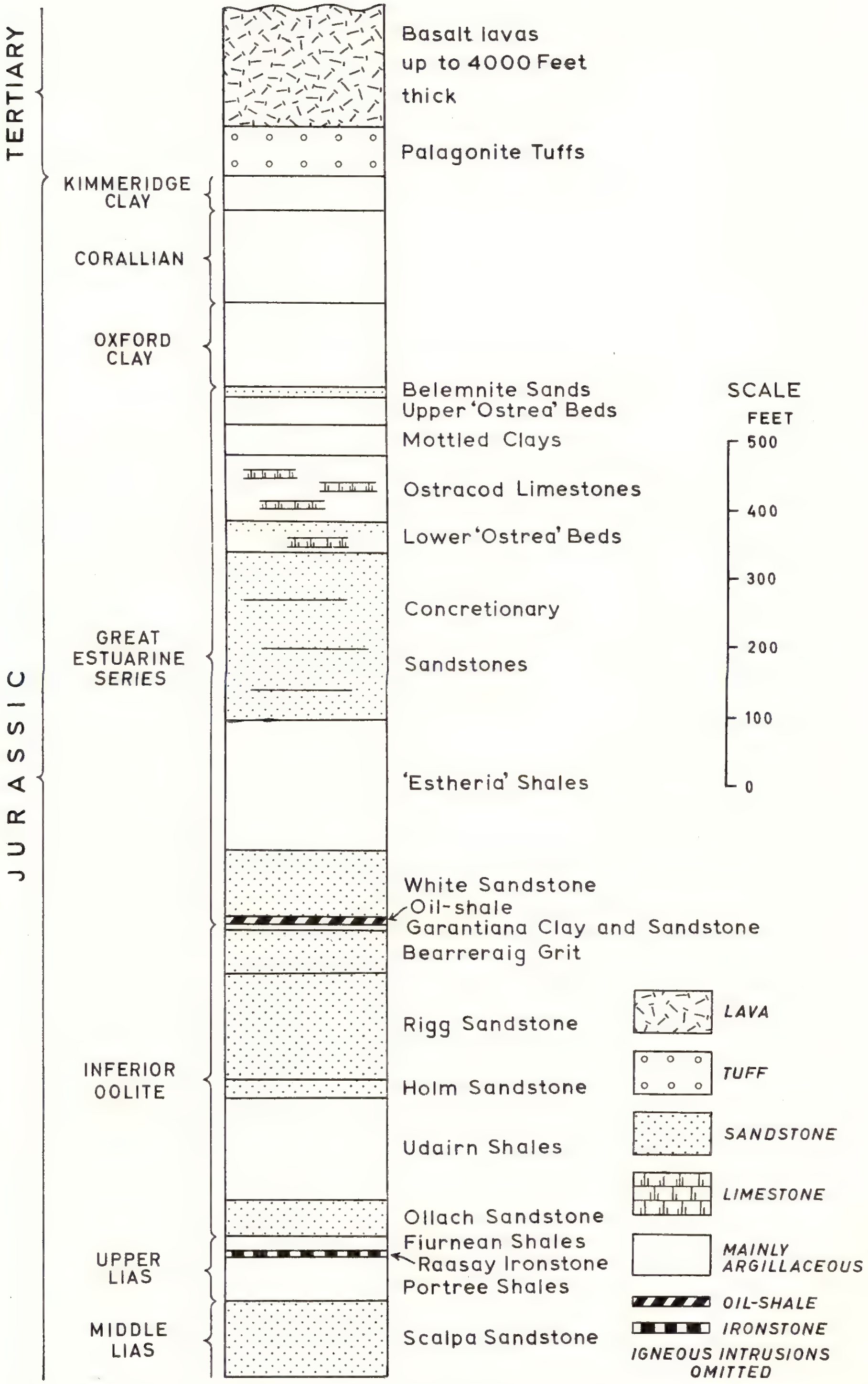


FIG. 2. *Generalized vertical section of sedimentary and volcanic rocks exposed in Northern Skye*

After the cessation of this extrusive phase, magma was introduced into the Jurassic sediments to form a great series of dolerite sills and some dykes. Later still the whole area was extensively block-faulted, tilted slightly to the west, and invaded by a vast number of dolerite dykes.

In the late Tertiary there was deep weathering and extensive erosion, particularly of the lavas, and landslips developed along the Trotternish scarp.

With the onset of glaciation in the early Pleistocene most of this debris was swept away by the ice. The main ice-flow was from the Highlands westwards but this was largely diverted by the eastern cliff and lava scarp into a north-flowing stream which was only able to resume its original direction in the extreme north of Trotternish.

With the retreat of the ice, landslipping again developed (Plate I), followed by the formation of thick peat over most of the area.

REFERENCES

HARKER, A. 1904. The Tertiary Igneous Rocks of Skye. *Mem. Geol. Surv.*

LEE, G. W. 1920. The Mesozoic Rocks of Applecross, Raasay and North-East Skye. *Mem. Geol. Surv.*

PEACH, B. N., HORNE, J., WOODWARD, H. B., CLOUGH, C. T., HARKER, A. and WEDD, C. B. 1910. The Geology of Glenelg, Lochalsh and South-East part of Skye. *Mem. Geol. Surv.*

Chapter II

JURASSIC: GENERAL, LIAS AND INFERIOR OOLITE

GENERAL ACCOUNT

THE JURASSIC SYSTEM consists of a lower marine series (Lias and Inferior Oolite) followed by estuarine deposits (Great Estuarine Series), after which marine deposits were again laid down (Oxford Clay, Corallian, Kimmeridge Clay).

Though forming the substratum over the whole of the area, the Jurassic rocks in North Skye are not very satisfactorily exposed. For the most part they underlie the Tertiary lavas or are distributed and altered by sills and dykes of the same volcanic episode; for the rest they are obscured in the north and west by peat and boulder clay and in the east by the great development of landslip from the lava-scarp. The remaining occurrences however, can be pieced together to give a connected account of the sequence of sedimentation in Jurassic times.

The earliest reference to the Jurassic rocks in Skye is to be found in Pennant's Tours in Scotland and the Hebrides in 1769 and 1772 (Pennant 1771, 1790) in which the author mentioned the occurrence of compressed ammonites in the strata at Duntulm. Observations on the Secondary rocks of Mull, Eigg and Skye are given in Jameson's Mineralogy of the Scottish Isles, published in 1800, and references to the Mesozoic rocks of the Hebrides generally are to be found in the letters of Mills (1790) and in the works of several foreign geologists, Saint-Fond (1799), Ami Boué (1820), Necker-de-Saussure (1821), von Oeynhausen and von Decken (1829), who visited these regions in the late 18th and early part of the 19th century.

Serious study of the Jurassic strata in Skye and the Hebrides generally owes its initiation to the work of Macculloch, who for so many years explored these regions in spite of the considerable difficulties of climate and transport. Since the publication of his Description of the Western Islands (Macculloch 1819, vol. 1, pp. 262-362), in which the Jurassic rocks of Skye were for the first time described, many eminent geologists have studied the sedimentary strata of this island. Sir Roderick Murchison during his visit to North Skye in 1827 (Murchison 1829, p. 358) examined an exposure of shales and shelly limestones in Staffin Bay to which he gave the name Loch Staffin Beds. The fossils collected on this occasion led him erroneously to correlate these beds with the Wealden of the Isle of Wight and the Isle of Purbeck.

In 1850 Forbes (1851, pp. 104-13) made a special visit to Staffin Bay in order to examine the beds described by Murchison. In his account of this visit he described the finding of 'numerous specimens of *Ammonites cordatus* and *Belemnites Owenii* and *Beaumontianus*, indicating the age of these shales beyond a question to be that of the Oxford clay' and '*beneath* them in conformable succession . . . yellowish crumbly limestone and shale with estuary fossils' (p. 106).

These fossils from below the Oxford Clay were described by Forbes and were regarded as characteristic of the estuarine Loch Staffin Beds and consequently of what is now called the Great Estuarine Series. The publication of this work has unfortunately led to considerable misunderstanding for three reasons; firstly the correct designation of the locality is Staffin Bay, there is no Loch Staffin; secondly, several of the species described by Forbes as typically estuarine had previously been recorded by Phillips under other names from the marine 'Kellaways' of Yorkshire; thirdly the so-called Loch Staffin Beds are in the nature of passage beds to the marine Oxford Clay and are by no means typical of the Skye estuarine deposits as a whole. Consequently, though bearing the stamp of antiquity, the name Loch Staffin Beds is best avoided as being too fruitful of error (Anderson and Cox 1948).

James Bryce (1873), described the Great Estuarine and Oxford Clay strata of 'Loch Staffin', the 'Kelt Rock', Uig and Duntulm. Much of the confusion which has existed regarding the nature of the 'Loch Staffin Beds' must be attributed to Bryce. He described a section (Section VII on page 329) which is said to be at Loch Staffin and of which he stated "The section given by Prof. E. Forbes [1851, p. 106] is not in exact harmony with ours; but there is a general agreement" (p. 330). Bryce's section is clearly that given on p. 32 of this memoir and is three-quarters of a mile south-east of Rubha Garbhaig, and is not in Staffin Bay. Further this section is in the Concretionary Sandstones and the Lower '*Ostrea*' Beds and is entirely below (at least 120 ft) the section given by Forbes (p. 106) which represents the Upper '*Ostrea*' Beds and Belemnite Sands and is in Staffin Bay. There is no agreement whatever between the two sections. In the appendix to this paper new species of fossils were described by Tate (*in* Bryce 1873, p. 339) and some of Forbes's species were revised.

In a general account of the Mesozoic Rocks in the west of Scotland, Judd (1878, p. 722) introduced the name Great Estuarine Series for the sediments lying between the Inferior Oolite and the Oxford Clay, including the Loch Staffin Beds of Murchison.

References to the Jurassic Rocks in Skye are also to be found in a summary of the Mesozoic rocks in Scotland given by Lee and Pringle in 1932, and in W. J. Arkell (1933). Malcolm MacGregor (1934) added considerably to our knowledge of the Jurassic sediments in North Trotternish. He recognized for the first time the presence of shales of Corallian and Kimmeridge Clay age in Staffin Bay. Anderson (1948) and Anderson and Cox (1948) described the Algal beds in the Great Estuarine Series and the stratigraphy and palaeontology of the Great Estuarine Series of Staffin Bay. In his account of the Great Estuarine Series of the Inner Hebrides J. D. Hudson (1962) included their development in Northern Skye.

The Jurassic sediments exposed in N. Skye range from the Middle Lias to the lower part of the Kimmeridge Clay (Sequanian). The Lower Lias, though seen a few miles to the south and in Raasay, is not exposed in the present area.

The following major divisions are recognized:

	ft
Kimmeridge Clay	40
Corallian Shales	170
Oxford Clay	90
Great Estuarine Series	about 600
Inferior Oolite Sandstone	375
Upper Lias Shales	about 100
Middle Lias Sandstone	about 240

The zonal sequence adopted in this memoir is that proposed by Spath in 1939 as best fitting the sequence of ammonite faunas found in Skye.

MIDDLE LIAS

The Middle Lias, of Upper Pliensbachian or Domerian Age, consists of the Scalpa Sandstone, probably more than 100 ft thick. It falls within the Zone of *Pleuroceras spinatum*, the underlying Zone of *Amaltheus margaritatus* not having been recognized in northern Skye.

The Middle Lias, named the ' Scalpa Series ' by Judd since it constitutes the main mass of the Liassic rocks on the island of Scalpa, is extensively developed in the Hebrides. It consists primarily of a fine-grained, calcareous sandstone, white, yellow or greyish in colour, distinctly bedded towards the base but tending to be massive in the upper part. There are, however, intercalations of sandy shales, especially in the middle. Both the shale and sandstone are highly micaceous. A characteristic feature of these beds is the occurrence of numerous large calcareous doggers which may reach 6 ft in diameter. They are generally in the form of flattened ellipsoids, the surface of which frequently exhibits honeycomb weathering.

DETAILS

In North Skye the Middle Lias Sandstone is exposed in the eastern sea-cliff at intervals from Camastianavaig to Holm. It was first noted in the Portree area by Murchison in 1829. Later, Bryce (1873) described sections in the same area (his Tanna Point is now known as Udairn), at Camastianavaig, and Prince Charles's Cave. The beds were first mapped by H. B. Woodward in 1896 and in 1920 G. W. Lee added a number of notes to the map and gave a short account of the Middle Lias of Skye in the memoir on North-east Skye and Raasay (Lee 1920). Reference has also been made to these beds by Lee and Pringle (1932), Arkell (1933) and Richey (1935).

The most southerly exposures of the Middle Lias in North Skye are in the Portree area. At Creagan na Sgalain, the promontory east of Camastianavaig, the topmost beds appear from below sea-level. They consist of yellowish calcareous sandstone and sandy shale with *Pseudopecten aequivalvis* (J. Sowerby), *Gryphaea cymbium* Lamarck, *G. gigantea* J. Sowerby and *Tetrarhynchia tetrahedra* (J. Sowerby). Four hundred yards further north they are sandstones with doggers, but beyond this point they are hidden beneath scree and landslip, except for isolated reefs in the beach, until Bryce's section at Udairn is reached. Here, immediately east of three conspicuous dykes the Middle Lias consists of a greenish sandstone with doggers and abundant *Pseudopecten aequivalvis*.

Further west, near the Scarf Caves, the Middle Lias comprises two distinct sedimentary groups, the upper part a hard sandstone with doggers 40 ft thick, the lower a soft grey shaly sandstone with doggers. *Tetrarhynchia*, *Pseudopecten* and fragmentary ammonites are abundant in the upper portion, which Bryce probably correctly assigned to the *Paltopleuroceras spinatum* Zone. Tate in his appendix to

Bryce's paper (Bryce 1873, pp. 344–5) listed a number of fossils from these beds on the basis of which he assigned the upper part to the *Paltopleuroceras spinatum* Zone and the lower to the *Amaltheus margaritatus* Zone. From the basal beds he identified *Prodactylioceras davoei* (p. 343) but this record has not been confirmed by later work. The sections are almost entirely in landslipped and broken ground so that exact measurements are impossible but the field-evidence suggests that only the upper part of the Scalpa Series is visible. In Raasay, recent work by Howarth (1956) has shown that the *Pleuroceras spinatum* Zone occupies 133 ft 10 in of strata and the *Amaltheus margaritatus* Zone 140 ft, whereas the thickest section in the Middle Lias in Skye, that near Holm Island, shows only 100 ft of sandstone. At Udairn only about 60 ft of Middle Lias is exposed above sea-level, all of which is sandstone like that forming the bulk of the *P. spinatum* Zone and the upper 28 ft of the *A. margaritatus* Zone in Raasay, and with no indication at the base of shaly beds like those which comprise the lower three-quarters of the *A. margaritatus* Zone and much of the *Prodactylioceras davoei* and *Tragophylloceras ibex* zones.

At Scorr Skerry, west of the Scarf Caves, the Middle Lias sandstones are faulted down to the west and are not seen again until they appear from below sea-level about half a mile north of Beal Point (Rubha na h-Airde Glaise), north of Portree. Northwards for three miles these beds form a sea-cliff often covered by scree and slip but here and there, as at Prince Charles's Cave, the highest beds, which are crinoidal and contain nests of Rhynchonellids, can be examined.

Bryce (1873, p. 326) gave a section at this point and described the Middle Lias as 'Close-grained hard calciferous sandstone, with intercalated, slightly ferruginous bands, and fossiliferous in the lower part chiefly. Thickness indeterminate, as it is continued under the sea-line. The leading fossils are, in the *Ammonites-spinatus* zone; *A. spinatus*, rare; *Belemnites paxillosus* common, . . . *Pecten aequivalvis*, common; . . . *Rhychonella tetrahedra*, very common . . .'

The most northerly exposures of the Middle Lias are on the beach opposite and south-west of Holm Island and here again the sandstones are very fossiliferous.

Woodward (Lee 1920, p. 29) noted that the upper beds of the Scalpa Series in Skye, as in Raasay, contained both spinate and annulate ammonites indicating that the upper few feet of the sandstone should be classed as Upper Lias. This observation has been confirmed in Raasay by Howarth (1956, p. 362) who recorded 6 ft of 'Sandstone, massive with some calcified parts; *Dactylioceras* spp. indicating the Tenuicostatum Zone'.

Since the *D. tenuicostatum* Zone is apparently missing from the base of the Upper Lias it may be entirely within the underlying sandy beds. But, as Buckman (*in* Lee 1920, p. 76) has pointed out, the lowest 14 ft of the Upper Lias has been insufficiently explored and Dactyliocerates of the *holandei* and *athleticum* types occur from 6 ft below the top of the Scalpa Sandstone to some 40 ft above.

UPPER LIAS

The succession in the Upper Lias is as follows:

Fiurnean Shales	(? *Lytoceras jurense* Zone)=Dun Caan Shales of Raasay
non sequence	(*Hildoceras bifrons* Zone not recognized)
Raasay Ironstone	
Portree Shales	(*Harpoceras falcifer* Zone and perhaps *Dactylioceras tenuicostatum* Zone)

The beds fall within the Toarcian Stage.

In Skye and Raasay the lowest zone found in the Upper Lias, that of *Dactyliocerus tenuicostatum*, may also include the uppermost six feet or so of the Scalpa Sandstone. The Upper Lias itself consists entirely of soft, dark micaceous shale with occasional calcareous bands and nodules and a two-foot band of ironstone, the equivalent of the Raasay Ironstone.

Details

Owing to the nature of the deposit the Upper Lias is nowhere clearly exposed, being usually more or less covered by slipped masses of the overlying rocks; thus its full thickness is not seen in any one place.

The most southerly exposure of the Upper Lias is at Creagan na Sgalain east of Camastianavaig. Here the shales are only 12 ft, and 400 yd farther north 5 ft thick and badly crushed. These localities are however involved in the Ben Tianavaig landslip so that a complete exposure of such incompetent strata is hardly to be expected.

To the north, 200 yd south of Udairn, Upper Lias shales with calcareous lenticles and ammonites (*Dactylioceras* and *Harpoceras*) are again exposed and still only 12 ft thick, but north of the Udairn Fault at least 40 ft of shale can be seen. North of Portree, below Sithean Bhealaich Chumhaing, the cliff-section exhibits 75 ft of Upper Lias shales whilst some 700 yd further north the following section is exposed:

	ft
Upper Lias	
Micaceous dark weathering shale	about 40
Oolitic Ironstone (slipped?)	1
Grey micaceous, ferruginous shale with small irregular nodules of limestone and a layer of *Posidonia bronni* at the base	3
Soft, micaceous, light grey shale full of *Dactylioceras*, broken and slipped	17?
Middle Lias	
Sandstone with doggers	60

The most northerly, and best exposure of the Upper Lias is a little above sea-level at the foot of the cliff opposite Holm Island and also a few hundred yards to the south. Here Mr. Tait discovered a thin band of jet closely associated with ammonites *Harpoceras* aff. *exaratum* (Young and Bird) and *Eleganticeras elegantulum* (Young and Bird), which indicate a horizon in the *H. exaratum* Subzone. It is interesting to note that the well-known Jet Rock horizon of Yorkshire is also in this subzone. This jet band is estimated to be about 14 ft above the top of the Scalpa Sandstone, thus below it there is ample room for deposits of the *D. tenuicostatum* zone. The *H. exaratum* fauna continues for two feet or so above the jet band and then for about 30 ft, i.e. to the top of the section exposed at this point, the shales belong to the *H. falcifer* Zone. In the first 10 ft of this zone the fauna consists mainly of ammonites: *Dactylioceras* cf. *anguinum* (Reinsch), *D.* cf. *crassiusculum* (Simpson) *D.* cf. *holandrei* (d'Orbigny) and *Harpoceras* aff. *mulgravium* (Young and Bird). A line of calcareous nodules at about 10 ft up contained *D.* cf. *gracile* (Simpson), *D.* cf. *holandrei*, *Coeloceras* cf. *foveatum* (Simpson), a *Harpoceras* of the *falcifer* type and *Harpoceratoides*, together with the gastropods *Natica adducta* (Phillips) and *?Pleurotomaria actinomphala* (Deslongchamps). In the shale surrounding these nodules *Phylloceras sp.*, *D. gracile ?*, *Astarte sp.*, *Lucina sp.*, and *Inoceramus sp.* were found. Three feet higher were nodules with numerous *Dactylioceras*, in particular *D.* cf. *vermis* (Simpson) which also occurred in rusty, decalcified nodules a few feet higher still in the sequence. *D.* cf. *holandrei* recurs in abundance above this level accompanied by *Pseudolioceras ?* and cf. *Harpoceras*. Finally, about 8 ft below the position of the Raasay Ironstone *D.* cf. *athleticum* (Simpson) was recovered. Nothing is known of the fauna in this 8 ft of shale below the ironstone position.

Borings put down by Messrs. Baird near the mouth of the Bearreraig River showed the ironstone to be 5 ft 9 in thick at this locality. In Raasay the ironstone is a sideritic chamosite-oolite, but in Skye is poor iron-carbonate rock with an average iron-percentage of 11·96, too low to be of economic value. The only fossils seen are the belemnite *Dactyloteuthis digitalis* (Phillips), several of which are rounded and worn, which supports Buckman's suggestion that the ironstone is a remanié deposit.

The shale above the ironstone is more arenaceous and harder than that below, and its fauna shows it to be Aalenian in age (*?Lytoceras jurense* Zone). Thus, as in Raasay there is a considerable non-sequence at the top of the ironstone and the Yeovilian and part of the Whitbian are missing. The fauna consists largely of species of *Cotteswoldia* e.g. *C. superba* S. S. Buckman, *C. costulata* (Zeiten), *?C. crinita*, S. S. Buckman, *?C. misera* S. S. Buckman, and *?Walkericeras lotharingicum* (Branco), found 3 ft above the ironstone.

Between Holm Island and the Bearreraig River the generalized section is:

		ft
	Sandstone (base of Inferior Oolite)	50
Fiurnean Shales (Aalenian)	Sandy shales (no fossils recorded)	12
	Sandy shales (*?Lytoceras jurense* or *Pleydellia aalensis* Zone)	13
	non-sequence	
Raasay Ironstone (*Frechiella subcarinata* Subzone)		2 to 5¾
Portree Shales (Whitbian)	Micaceous shales with thin limestone bands and nodules (*H. falcifer* Zone)	22–55
	(*H. exaratum* Subzone)	2
	Jet Band	1
	Micaceous shales (?part *H. exaratum* Subzone) (?part *D. tenuicostatum* Zone)	14
Scalpa Sandstone		

INFERIOR OOLITE

The succession in the Inferior Oolite is as follows:

Garantiana Clay and Sandstone (*Garantiana garantiana* Zone)
Bearreraig Grit (*Strenoiceras subfurcatum* Zone)
Rigg Sandstone (*Stephanoceras humphresianum* Zone)
Holm Sandstone (*Otoites sauzei* Zone)
Udairn Shales (*Sonninia sowerbyi* Zone)
Ollach Sandstone (*Ludwigia murchisonae* and *Leioceras opalinum* zones).

The Inferior Oolite (Bajocian) of the Inner Hebrides consists almost entirely of marine deposits, mainly sandstones, laid down not far from land as the common occurrence in them of fossil drift-wood testifies. The evidence from Skye and Raasay together shows that the succession is complete from the *L. urense* Zone of the Upper Lias to the *G. garantiana* Zone of the Inferior Oolite. If deposits of the *Parkinsonia parkinsoni* Zone are present they are not represented by marine strata but perhaps by the Oil-Shale and White Sandstone at the base of the Great Estuarine Series. The former appears to contain, in Skye, only *Neomiodon* and plant remains. Recently, however, Forsyth (1959) has found marine fossils in beds which he believed to be of this age near Storav's Grave in Raasay.

The Inferior Oolite is well developed in N. Skye, forming precipitous cliffs from Camastianavaig to Upper Tote, but the nature of the ground makes zonal collecting difficult. Enough has been done, however, to allow direct comparison with the sequence in Raasay where the beds are more accessible.

There are certain differences both in sedimentation and distribution of fauna between Skye and Raasay but the general succession remains the same in both islands. The lithological sequence in N. Skye is:

GREAT ESTUARINE SERIES: (Oil-Shale)	ft
Garantiana Clay: Clay passing into black sandstone	5
Bearreraig Grit: Hard gritty calcareous sandstone full of shell fragments	about 50
Rigg Sandstone: Calcareous sandstone with numerous doggers	about 150
Holm Sandstone: Hard massive calcareous sandstone, variable, but usually about	30
Udairn Shales: Sandy calcareous shale with doggers	about 150
Ollach Sandstone: Hard calcareous sandstone with doggers	about 50
UPPER LIAS	

DETAILS

The most southerly outcrop of the Inferior Oolite in N. Skye forms the shore between Lower Ollach and Camastianavaig. Shaly sandstones with doggers emerge from below the Tertiary beds about 700 yd north of Lower Ollach and form a low cliff. The base of the sandstone is not seen but cannot be far below sea-level for the Inferior Oolite strata exposed here are not more than 15 ft thick and represent only the basal portion of the series. The greater part has been cut out by the overlap of the Tertiary sediments above.

At a point 400 yd N. of Creagan na Sgalain, east of Camastianavaig the Inferior Oolite is represented again by 15 ft of sandstone with doggers, belemnites and with phosphatic nodules at the base. It is overlain by a 2-ft greenish sandstone belonging to the Tertiary plant beds (see p. 75).

At Udairn the Ollach Sandstone and Udairn Shales are together about 150 ft thick; above these strata about 200 ft of massive white and yellow sandstone with doggers, the Holm and Rigg sandstones, are visible.

Northwards the lower shaly division (Udairn Shales) increases in thickness to 225 ft whilst the upper yellow sandstone thins to 150 ft.

North of Portree the Bearreraig Grit is well exposed at Port a'Bhata (Fig. 5) north of Ben Chracaig where it forms the top of the sea-cliff. It is here about 30 ft thick and crowded with belemnites, Rhynchonellids and lamellibranch shell fragments. The overlying *Garantiana* Clay is weathered back for 100 yd or so from the cliff top and hidden beneath scree and slip from the overlying White Sandstone and Palagonite Tuffs. Below the grit bed about 150 ft of yellowish sandstones with doggers are exposed, near the base of which is a band containing ammonites of the genus *Sonninia*. At the foot of the cliff a shaly fucoidal sandstone (Udairn Shales) with belemnites appears but is generally badly exposed. The Port a'Bhata section is in a block (horst) faulted off on both sides so that northwards the Bearreraig Grit is brought down almost to sea-level again but the whole thickness of the Inferior Oolite gradually emerges until at Sithean Bhealaich Chumhaing the full thickness is seen for the first time. There is however a great deal of scree and the section given below is a composite one measured in the cliff between Craig Ulatota and Fiurnean (Fig. 3).

Section in sea-cliff at Fiurnean

Tertiary:	ft
Palagonite Tuff	160
Sandstones with plant debris	60
Dolerite sill	18

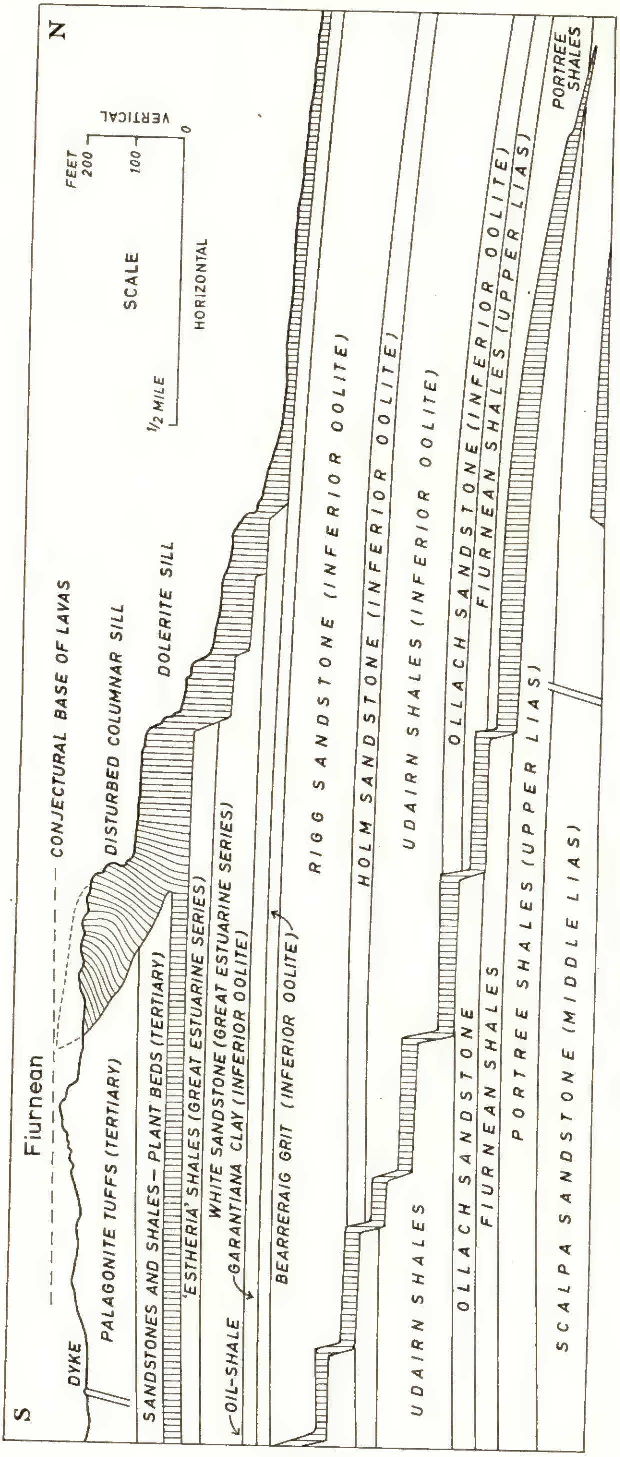
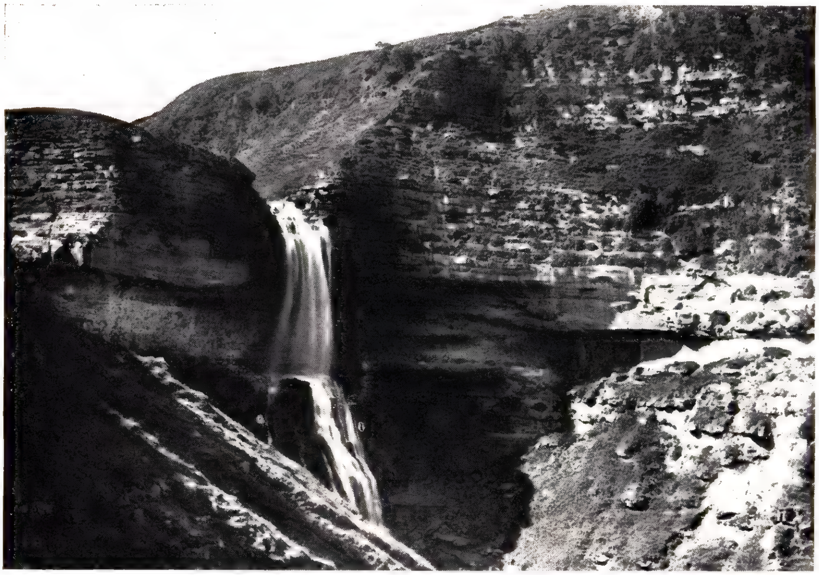

S
N
Fiurnean
DYKE
CONJECTURAL BASE OF LAVAS
DISTURBED COLUMNAR SILL
DOLERITE SILL
SCALE
FEET
200
100
0
VERTICAL
½ MILE
HORIZONTAL
PALAGONITE TUFFS (TERTIARY)
SANDSTONES AND SHALES— PLANT BEDS (TERTIARY)
'ESTHERIA' SHALES (GREAT ESTUARINE SERIES)
WHITE SANDSTONE (GREAT ESTUARINE SERIES)
OIL-SHALE
GARANTIANA CLAY (INFERIOR OOLITE)
BEARRERAIG GRIT (INFERIOR OOLITE)
RIGG SANDSTONE (INFERIOR OOLITE)
HOLM SANDSTONE (INFERIOR OOLITE)
UDAIRN SHALES
UDAIRN SHALES (INFERIOR OOLITE)
OLLACH SANDSTONE
OLLACH SANDSTONE (INFERIOR OOLITE)
FIURNEAN SHALES
FIURNEAN SHALES (UPPER LIAS)
PORTREE SHALES
PORTREE SHALES (UPPER LIAS)
PORTREE SHALES
SCALPA SANDSTONE (MIDDLE LIAS)

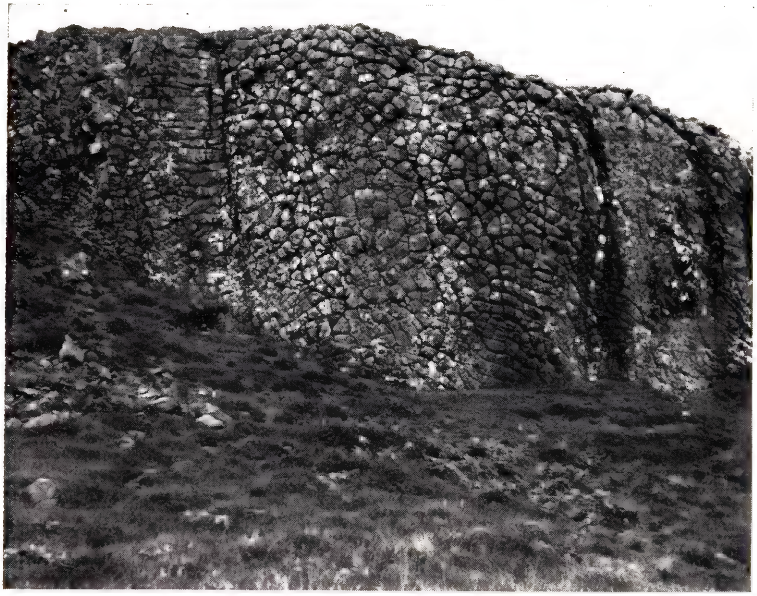
FIG. 3. *Section in sea-cliff at Fiurnean, 4 miles N.N.E. of Portree*

OXFORD POLYTECHNIC LIBRARY



(C2241)

A. BEARRERAIG, SIX MILES NORTH-NORTH-EAST OF PORTREE
Inferior Oolite sandstone giving rise to waterfall



(C3919)

B. LYNDALE POINT, 100 YD FROM SHORE, 1530 YD NORTH-NORTH-WEST OF LYNEDALE HOUSE
Dolerite dyke showing columnar jointing

Jurassic:	ft
Great Estuarine Series	
Black Shales ('*Estheria*' Shales)	40
White Sandstone	100
Bituminous sandy shale	3
Inferior Oolite	
Clay (*Garantiana* Clay)	7
Hard sandstone with belemnites, Rhynchonellids and shell fragments (Bearreraig Grit)	20
Soft yellow sandstone with doggers, Stepheoceratids (Rigg Sandstone)	140
Hard calcareous sandstone (Holm Sandstone)	40
Soft, green-grey, sandy shale or shaly sandstone, *Sonninia* and large belemnites (Udairn Shales)	160
Beds of hard sandstone with doggers (Ollach Sandstone)	50
Upper Lias	
Sandy micaceous shale (Fiurnean Shales)	25
Soft dark shale (Portree Shales)	75
Middle Lias	
Hard calcareous sandstone (Scalpa Sandstone)	seen 100

Much the most accessible of the Inferior Oolite outcrops are those in Bearreraig Bay. On the south side of the river a wave-cut platform of flaggy sandstone (Ollach Sandstone) offers the richest collecting in the formation. Here Lady Murchison collected the type specimen of *Ludwigia murchisonae* (J. de C. Sowerby), the species which gave its name to the zone.

In addition to the type a large number and variety of Ludwigioids are to be found. Buckman (*in* Lee 1920, p. 77) compared this fauna with that of the Wild Bed of Chideock near Bridport, in Dorset, and further commented on the rarity or absence of certain southern species in the *L. murchisonae* beds of Skye, in particular on the entire absence of the very massive forms of which *L.* (*Kiliania*) *armipotens* S. S. Buckman is typical. There is one specimen in the Edinburgh collections, however, which was obtained from a loose block between Holm Island and Bearreraig Bay which L. F. Spath thought was related to *L.* (*K.*) *armipotens* so that further collecting may disclose the presence of this and other southern species.

In Raasay ammonites of the *Leioceras opalinum* Zone (*Tmetoceras scissum* Zone of Buckman) were found in large numbers 3 ft below the *L. murchisionae* Zone, being mainly species of *Leioceras*. In Skye the presence of this zone was no more than indicated by a few specimens of *Leioceras* collected by the author during the last survey, one of which was identified by Spath as *L.* aff. *bifidatum* (S. S. Buckman). Its thickness and exact relationship to the zones above and below could not be determined.

The known fauna of the *L. murchisonae* Zone at Bearreraig Bay is as follows, r denoting rare and c common:

Brasilia decipiens (S. S. Buckman), *Ludwigia ambigua* S. S. Buckman r, *L.* (*Kiliania?*) *sp. nov.*, aff. *armipotens* S. S. Buckman r, *L.* (*Apedogyria*) *baylei* (S. S. Buckman) r, *L.* (*Hyattia*) *brasili* (S, S. Buckman), *L.* (*Cosmogyria*) *extralaevis* (Quenstedt), *L.* (*Apedogyria*) aff. *falcata* (Quenstedt) r, *L. gradata* S. S. Buckman, *L. laevigata* S. S. Buckman, *L.* (*Ludwigina*) *literata* (S. S. Buckman) var. r, *L. murchisonae* (J.

Sowerby), r, *L.* (*Cosmogyria*) *obtusa* (Quenstedt), *L. patellaria* (S. S. Buckman) r, *L.* (*Crikia*) *reflua* (S. S. Buckman) c, *L.* (*Apedogyria*) *subcornuta* (S. S. Buckman) c, *L.* aff. *tuberculata* (S. S. Buckman), *L.* (*Ludwigina*) *umbilicata* (S. S. Buckman) c, *Stephanoceras* aff. *cosmopolitum* (Moericke) r, and *Belemnopsis* cf. *canaliculatus* auctorum (*non* Phillips).

North of Bearreraig Bay fallen blocks of sandstone have yielded ammonites which indicate the presence of higher zones, but systematic collecting from these precipitous cliffs is virtually impossible and so far it has not proved possible to delimit them with any accuracy.

The dip of the beds however, brings higher horizons down to sea-level northwards and in the last survey an attempt was made to collect fossils *in situ* at least up to the middle of the Rigg Sandstone.

The lowest 40 ft or so of the Udairn Shales, best seen below the lowest fall in the the Bearreraig River, appear also to belong to the *L. murchisonae* Zone. From loose blocks of these shales, just south of the river, the ammonites *Graphoceras* (*Ludwigella*) *arcitenens* (S. S. Buckman), *G.* (*Lucya*) *magnum* (S. S. Buckman), *G.* (*Ludwigella*) aff. *rudis* (S. S. Buckman), *G.* (*L.*) aff. *sublineatum* (S. S. Buckman) were collected. *Hyperlioceras* ('*Dissoroceras*') *excavatum* (S. S. Buckman) was found *in situ* 30 ft above sea-level and *Brasilia decipiens* (S. S. Buckman) 20 ft higher. These appear to indicate the presence of the *bradfordensis*, *concava* and *discites* zones of Lee (1920, p. 49) but not in the order given by him. Here they are regarded as the uppermost beds of the *L. murchisonae* Zone but could equally well be regarded as the basal portion of the *Sonninia sowerbyi* Zone.

The ammonite fauna of the upper half of the Udairn Shales consists almost entirely of species of *Sonninia*, only one of which, *Sonninia* aff. *mesacantha* (Waagen), recovered from just below the Holm Sandstone at Rubha Sughar, was *in situ*, the remainder, *S. carinodiscus* (Quenstedt), *S. sowerbyi* (Miller), and *S.* aff. *alsatica* (Haug) were collected from loose blocks. Lee (1920, p. 49) referred to a very large specimen which may be *Shirburnia trigonalis* S. S. Buckman and a single specimen of *Witchellia*, both collected from loose blocks but which probably came from the middle of the Udairn Shales.

The *Otoites sauzei* Zone is probably represented by the Holm Sandstone which forms the lowest sea-cliff from Rubha Sughar north to Upper Tote. The species *Otoites* cf. *bigoti* (Munier-Chalmas) Masske and *Poecilomorphus macer* S. S. Buckman collected from loose blocks north of Bearreraig Bay are the only indications that the zone is present.

North of Rubha Sughar the majority of the fallen rock must have come from the Rigg Sandstone; from these blocks an ammonite fauna indicative of the *Stephanoceras humphriesianum* Zone has been collected. *Stephanoceras* aff. *gibbosus* (S. S. Buckman), *S.* aff. *kretur* (S.S. Buckman), *S. humphriesianum* (J. de C. Sowerby), *Stemmatoceras* aff. *subcoronatum* (Quenstedt), were all found in loose blocks but *Skirroceras* cf. *nodosum* (Quenstedt) was collected *in situ* in the bed of the stream 2/3-mile south-west of Holm. In the Bearreraig River the middle fall is caused by a 30-ft bed of calcareous sandstone with large belemnites *Megateuthis* cf. *aalensis* (Voltz). The horizon appears to be in the *S. humphriesianum* Zone and Buckman was probably correct in correlating this bed with the Belemnite Beds of the Scarborough Limestone.

The Bearreraig Grit has not yielded any recognizable fossils though here, as in Raasay, it is crowded with broken lamellibranch fragments. It may however, represent the *Stenoiceras subfurcatum* Zone as the *S. humphriesianum* beds are not far below and it is directly overlain by the *Garantiana* Clay. A mile and a half north-east of Portree this subdivision exhibits large-scale slump bedding.

Inland the Bearreraig Grit is exposed in the Bearreraig River at the north end of Loch Leathan.

At Holm the Bearreraig Grit is succeeded by a plastic clay identical with that of the same age in Raasay. It is rarely exposed but a single specimen of *Garantiana* has been found in it. North of Bearreraig and westwards the clay passes laterally into a soft black sandstone which may be seen on the east side of Loch Leathan where it is 8 ft thick.

This sudden change of facies marks the Vesulian transgression which in southern England followed an important orogenic episode. In Skye and Raasay, however, this marine transgression was short-lived for even if the Oil-Shale above is included with the *Garantiana* Clay, estuarine conditions were established after not more than 30 ft of strata had been laid down. The *Garantiana* Clay passes upwards into a bituminous shale at the base of the Great Estuarine Series.

REFERENCES

ANDERSON, F. W. 1948. Algal beds in the Great Estuarine Series of Skye. *Proc. Roy. Phys. Soc. Edin.*, **23**, 123-42.

ANDERSON, F. W. and COX, L. R. 1948. The 'Loch Staffin Beds' of Skye, with notes on the molluscan fauna of the Great Estuarine Series. *Proc. Roy. Phys. Soc. Edin.*, **23**, 103-22.

ARKELL, W. J. 1933. *The Jurassic System in Great Britain.* Oxford.

BOUÉ, A. 1820. *Essai géologique sur L'Écosse.* Paris.

BRYCE, J. 1873. On the Jurassic rocks of Skye and Raasay. *Quart. J. Geol. Soc.*, **29**, 317–51.

FORBES, E. 1851. On the Estuary Beds and the Oxford Clay at Loch Staffin in Skye. *Quart. J. Geol. Soc.*, **7**, 104-13.

FORSYTH, I. H. 1959. A marine shell-bed near the base of the Estuarine Series in Raasay. *Trans. Edin. Geol. Soc.*, **17**, 273-75.

HOWARTH, M. K. 1956. The Scalpa Sandstone of the Isle of Raasay, Inner Hebrides. *Proc. Yorks. Geol. Soc.*, **30**, 353-70.

HUDSON, J. D. 1962. The Stratigraphy of the Great Estuarine Series (Middle Jurassic) of the Inner Hebrides. *Trans. Edin. Geol. Soc.*, **19**, 139-65.

JAMESON, R. 1800. *Mineralogy of the Scottish Isles*, 2 vols. London and Edinburgh, especially **2**, 70-97, 107-19.

JUDD, J. W. 1878. The secondary rocks of Scotland. Third Paper. The strata of the Western Coast and Islands. *Quart. J. Geol. Soc.*, **34**, 660-743.

LEE, G. W. 1920. The Mesozoic Rocks of Applecross, Raasay and North-East Skye. *Mem. Geol. Surv.*

—— and PRINGLE, J. 1932. A synopsis of the Mesozoic rocks of Scotland. *Trans. Geol. Soc. Glasgow*, **19**, 158-224.

MACCULLOCH, J. 1819. *A Description of the Western Islands of Scotland including the Isle of Man.* 3 vols. London.

MACGREGOR, MALCOLM. 1934. The sedimentary rock of North Trotternish, Isle of Skye. *Proc. Geol. Assoc.*, **45**, 389-406.

MILLS, A. 1790. On the Strata and Volcanic Appearances in the North of Ireland and Western Islands of Scotland. *Phil. Trans. Roy. Soc.*, **80**, 73-100.

MURCHISON, R. I. 1829. Supplementary remarks on the strata of the Oolite Series, and the Rocks associated with them in the Counties of Sutherland and Ross, and in the Hebrides. *Trans. Geol. Soc.* (2), **2**, 353-68.

NECKER-DE-SAUSSURE, L. A. 1821. *Voyage en Écosse et aux Iles Hebrides*, **3**, 24-5. Paris.

PENNANT, T. 1774. *A Tour in Scotland*, 1769. Warrington.

—— 1790. *A Tour in Scotland and Voyage to the Hebrides;* 1772. 2 Parts. London.

RICHEY, J. E. 1935. Scotland: The Tertiary Volcanic Districts. *British Regional Geology. Geol. Surv.* (3rd Edition with revision by A. G. MacGregor and F. W. Anderson, 1961).

SAINT-FOND, B. F. 1799. *Travels in England, Scotland and the Hebrides;* . . . 2 vols. London.

VON DECKEN, H. and VON OEYNHAUSEN, C. 1829. Die Insel Skye. *Archiv. f. Min.*, **1**, 56-104.

Chapter III

JURASSIC: GREAT ESTUARINE SERIES

GENERAL DESCRIPTION

THE FOLLOWING table gives details of the succession in the Great Estuarine Series in Skye and Raasay.

N. Skye (after Anderson 1948)	S.-E. Skye (Wedd *in* Peach and others 1910, p. 121) Hudson 1962, p. 150)	Raasay (Lee 1920; Hudson 1962, p. 147)
Belemnite Sands 25 ft Contain a marine fauna and appear to be of Kellaways age	Black Sandstone	Absent?
Upper '*Ostrea*' Beds 35 ft Probably a lenticular shell-bed of Cornbrash age	Absent	Absent?
Mottled Clays 43 ft No fauna but plant fragments. Possibly of Cornbrash age	Blue shaly marl up to 30-40 ft	Sandy limestone
Ostracod Limestones 90 ft	'*Paludina*' *scotica* Limestones 37 ft Shales and thin limestones 40 ft?	Limestones and Shales
Lower '*Ostrea*' Beds 60 ft	'*Ostrea*' *hebridica* Beds 17 ft	'*Ostrea*' *hebridica* Beds ?
Concretionary Sandstones 240 ft	'*Cyrena*' Limestones 70 ft	Calcareous Sandstones at least 120 ft
'*Estheria*' Shales 120 ft	'*Cyrena*' Shales 200 ft	'*Cyrena*' Shales and Sandstones 100 ft
White Sandstone 30-100 ft	White Sandstone 50 ft	White Sandstone 50 ft
Oil-Shale 10 ft	Oil-Shale 10 ft	Oil-Shale 8-10 ft

In Skye as in Scotland generally, the Great Oolite epoch was one during which estuarine conditions prevailed; fully marine conditions were re-established in the Cornbrash. The deposits laid down during this period were originally known as the Loch Staffin Beds after Staffin Bay where they were examined by Murchison (1829) who believed them to be fresh-water sediments of Wealden or Purbeck age. This name can, however, only be applied to the uppermost beds i.e. the Upper '*Ostrea*' Beds and Belemnite Sands which are exposed in Staffin Bay and, as Anderson and Cox (1948) have shown, contain a fauna of predominantly marine species.

In 1878, Judd introduced the term Great Estuarine Series, by which name these have been known ever since.

In Raasay where the series is badly exposed Lee (1920) was unable to recognize the Skye subdivisions and followed H. B. Woodward in thinking that only the lower part of the Great Estuarine Series was present in that island. There is reason to believe however, (Anderson *in* Richey and others, 1961) that the succession in Raasay is not very different from that in N. Skye.

In 1934 MacGregor described the upper part of the Concretionary Sandstones as exposed near Rubha Garbhaig. More recently Hudson (1962, 1963, 1963a) has studied the stratigraphy and fauna of the Great Estuarine Series in the Hebrides including Skye.

In the Great Estuarine Series of North Skye a great variety of sediments is represented, comprising sandstones, frequently with calcareous doggers, limestones, cementstones, marls and shales. Cyclic sedimentation is evident throughout. The *Garantiana* Clay at the top of the Inferior Oolite passes upwards into a bituminous shale at the base of the Great Estuarine Series. The lowest 7 ft form a true oil-shale whilst the uppermost 3 ft are sandy. Northwards the oil-shale passes into a black sandstone. In Skye this bed has only yielded *Protomiodon* and plants, but according to Forsyth (1959), in Raasay a quarter of a mile north-east of Storav's Grave it contains a marine fauna. The White Sandstone overlies the Oil-Shale.

Wedd (*in* Peach and others 1910, p. 117), in Strathaird grouped this sandstone with the Inferior Oolite on the grounds of its similarity to the sandstones below and because of its gradual downward passage into the shale. Lee, however, (1920) included the Oil-Shale and White Sandstone in the Great Estuarine Series. Since no diagnostic fossils have yet been found in either stratum it is not possible to settle the question. Wedd's argument that there may have been some oscillation between marine and estuarine conditions in the highest Inferior Oolite has a degree of support from the field evidence. Certainly the three major sedimentary changes in this part of the succession are: 1. Upper Lias Shales 2. *Garantiana* Clay 3. '*Estheria*' Shales.

Above the White Sandstone the '*Estheria*' Shales consist of numerous shale-limestone-sandstone rhythms. The Concretionary Sandstones provide five repetitions of a shale-sandstone rhythm, the Ostracod Limestones show a coarser grained repetition of the '*Estheria*' Shales and finally the Mottled Clays-Belemnite Sands cycle occurs before the oncoming of the characteristic shale-calcareous mudstone rhythm of the Oxford Clay–Corallian–Kimmeridge Clay sequence (Fig. 4).

Though fossils are frequently abundant, they are usually badly preserved and the number of species represented is few. Except for the two uppermost subdivisions the freshwater and brackish-water faunas appear to be the same

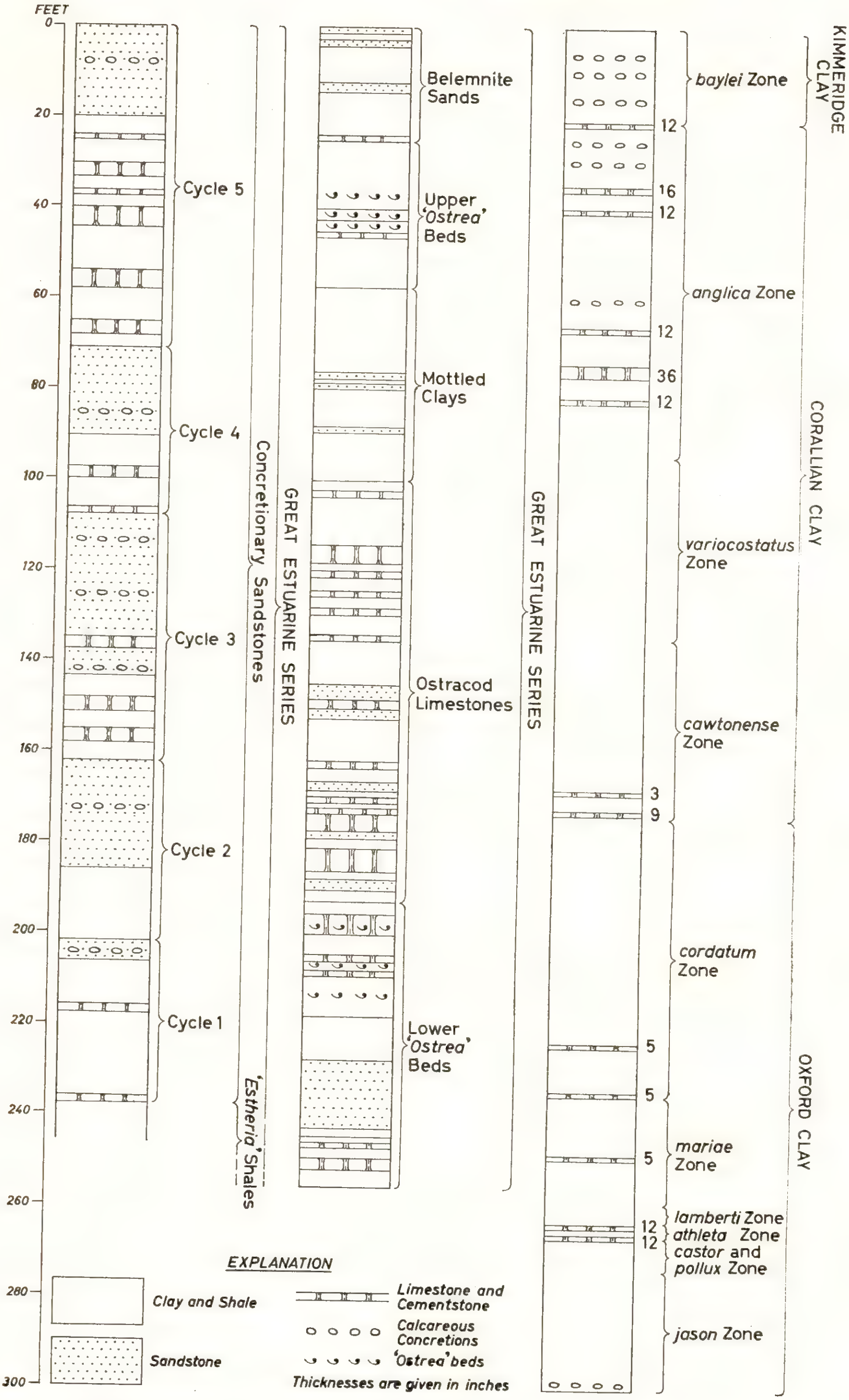


FIG. 4. *Sections showing the sequence of strata in the Concretionary Sandstones, Lower 'Ostrea' Beds, Ostracod Limestones, Mottled Clays, Upper 'Ostrea' Beds, Oxford Clay, Corallian and Kimmeridge Clay*

throughout so that no zonal subdivision seems possible unless by the use of ostracods.

Many sections of the Great Estuarine Series are recorded in detail on the six-inch maps and also by Anderson (1948) and Anderson and Cox (1948). In Anderson's paper are sketch-maps giving details of the occurrence of particular beds and especially the development of algal horizons in the '*Estheria*' Shales, in the Lower '*Ostrea*' Beds and in the Mottled Clays.

DETAILS

OIL-SHALE

The Oil-shale reaches sea-level at Inver Tote, where there are two black sandstones separated by 2 in of shale. The upper Sandstone is the lateral development of the Oil-shale and the lower, which contains marine fossils, of the underlying *Garantiana* Clay of the Inferior Oolite. The clay and shale are eroded back to form a conspicuous ledge between the Bearreraig Grit and the White Sandstone above.

Lee (1920, p. 56) thought that southwards from Portree the Oil-shale became an impure coal, but the coal (lignite) seen at Camastianavaig is in the Tertiary plant beds at the base of the Palagonite Tuffs and the Oil-shale is cut out by the Tertiary overstep before Camastianavaig is reached.

WHITE SANDSTONE

The White Sandstone in Strathaird is slightly calcareous and includes a few seams of quartz pebbles. In North Skye it is poorly exposed but at Port a'Bhata is a soft white, somewhat greenish, often waterlogged sandstone composed of angular quartz grains and virtually without cement. At Portree and again at Holm it is 100 ft thick (Fig. 5) but thins northwards gradually until where last seen at Inver Tote it is only 30 ft thick (Fig. 6). Southwards, it is rapidly overstepped by the Palagonite Tuffs which at Camastianavaig rest on the lower beds of the Inferior Oolite.

The upper two thirds of the White Sandstone is well seen in Rigg Burn.

Section in Rigg Burn

	ft
Dolerite Sill	2½
'*Estheria*' Shales, black shale	9
White Sandstone, soft sandstone	10
Shaly sandstone	10
Sandstone with doggers	10
Hard, irony sandstone	1½
Dark, sandy, calcareous shale	5
Hard, irony sandstone	1½
Dark, sandy calcareous shales	5
Irregular, irony, calcareous sandstone	2½
Black, sandy, calcareous shales	20
Hard sandstone causing waterfall	2
Shaly sandstone with hard bands	

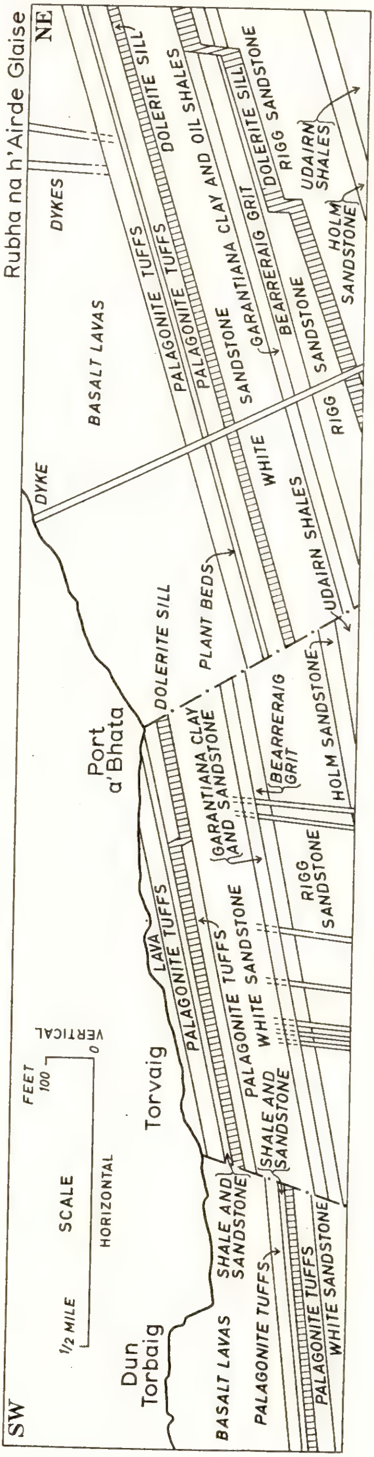


FIG. 5. *Section in sea-cliff on north side of Portree Bay*

'ESTHERIA' SHALES

The White Sandstone is succeeded abruptly by dark calcareous shales. The junction is best seen in the Lealt River where, in the lower gorge, these shales are seen to rest on a coarse grit 2 ft 8 in thick at the top of the White Sandstone. Here they are thin papery shales with thin dark limestone ribs, bands of 'beef' (fibrous calcium carbonate) and layers of crushed shells usually *Neomiodon* ('*Cyrena*') *spp*. Some bedding planes are literally covered with a multitude of *Euestheria* carapaces, or, less frequently, with ostracods.

In 1948 Anderson and Cox described the lamellibranch *Mytilus* (*Praemytilus*) *strathairdensis* from the '*Estheria*' Shales in Strathaird but the species was not known from Northern Skye. Since then J. D. Hudson (1963) has recorded it in the *Mytilus* Shales (the lower part of the '*Estheria*' Shales of the present memoir) of Eigg and Raasay. From the '*Estheria*' Shales (upper part of the '*Estheria*' Shales of the present memoir) of Skye, Raasay and Eigg, Hudson (1963) has also recorded *Cuspidaria ibbetsoni* (Morris), *Modiolus* cf. *imbricatus* (J. de C. Sowerby), *Placunopsis socialis* Morris and Lycett, *Procerithium spp*., cf. *Quenstedtia sp*., *Tornus praecursor* (Tate) as well as the ubiquitous *Euestheria murchisonae* (Jones) and *Liostrea hebridica* (Forbes). A few yards upstream from the road-bridge, the shales include a group of limestones rather thicker than usual. One of these, a dark brecciated bed 9 in thick, contains Charophyte gyrogonites and indeterminate algal growths (Anderson, 1948). Hudson (1963) has recently investigated the fauna of the '*Estheria*' Shales in Eigg, Skye and Raasay and has recorded several molluscan species in addition to the *Mytilus strathairdensis* first found by Anderson in Strathaird (Anderson and Cox 1948).

Section in the Lealt River

	ft	in
Base of Concretionary Sandstones		
15. '*Cyrena*' (*Neomiodon*) shales and limestones, poorly exposed, about	20	0
Gap of 90 ft—probably shales		
14. Black shale	3	0
13. Dark shaly limestone		3½
12. Paper shale with *Neomiodon*	1	10
11. Dark shaly limestone		3
10. Black paper shales	2	4
9. Dark shaly limestone		2½
8. Black paper shales	2	7
7. Limestone with *Neomiodon*	1	2
6. Black shale	1	0
5. Dark brecciated limestone with cementstone pebbles and algal concretions. *Chara*.		9
4. Dark shales, *Euestheria*, *Neomiodon sp*., ostracods	30	0
Dolerite sill .. about	150	0
3. Dark shales with *Euestheria* and *Neomiodon sp*.	21	0
Dolerite sill	7	0
2. Dark shales with *Euestheria* and *Neomiodon sp*.	15	0
Dolerite sill 1 ft 6 in to	2	9
1. Dark shales with *Euestheria*	24	0
Coarse Grit, top of White Sandstone	2	8

In Trotternish the '*Estheria*' Shales are overlapped by the Tertiary lavas at Sithean Bealaich Chumhaing and are not seen south of this point until they reappear in Strathaird. To the north for just over two miles they crop out as a wide flat bench in the cliff with the White Sandstone scarp below and with a 25-ft thick dolerite sill forming a low steep bluff at the back. Exposures are few and poor but it is evident that only about 40 ft are exposed whereas at Inver Tote they are not less than 120 ft thick (Fig. 6).

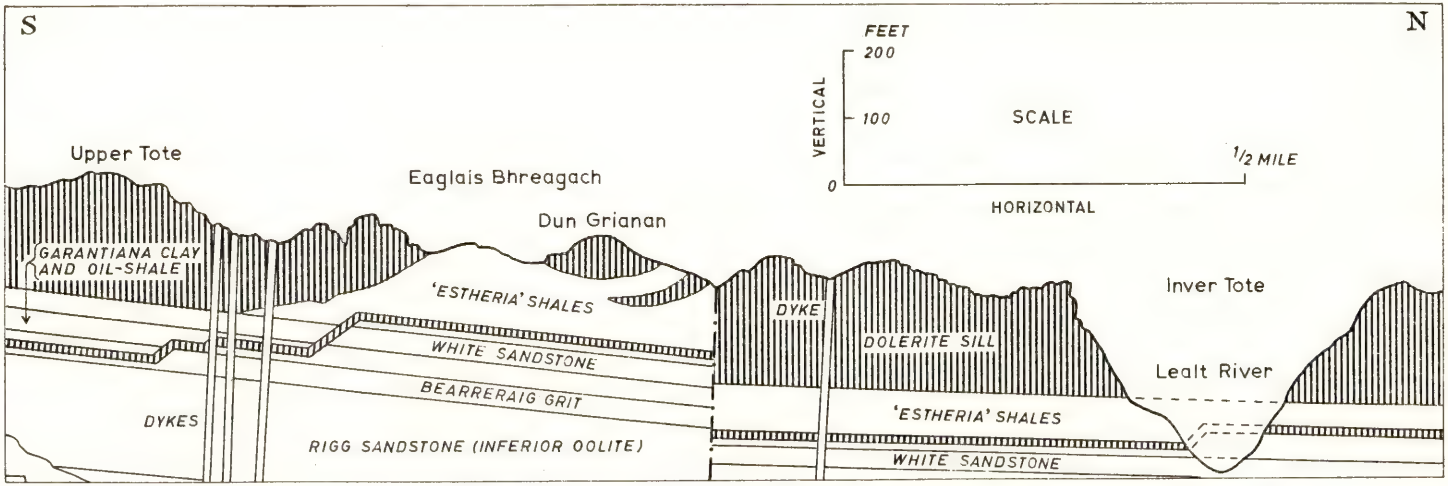


FIG. 6. *Section in sea-cliff between Upper Tote and Inver Tote*

At the latitude of Armishader the '*Estheria*' Shales outcrop turns inland under a tongue of sill and gives rise to a wide marshy flat at the southern end of Loch Leathan. They underlie the western half of the loch and again passing beneath a leaf of sill follow the cliff top northwards as far as Rigg Burn. They are exposed in two unnamed streams one 2/3 miles and the other 1¼ miles south of Rigg. At the most northerly of these two localities about 50 ft of shale are exposed containing a 2½-in thick '*Ostrea*' limestone, cementstones and a line of septarian nodules. A thousand yards north along the strike of the shales they are again seen in the southern tributary of Rigg Burn. Here two thin leaves of sill, the upper 1 ft 9 in and the lower 2 ft 0 in thick, cause a waterfall in the stream. They are separated by 1 ft 3 in of shale and about 3 ft of shale is exposed below them. Twenty yards further north the two leaves of sill have joined and again produce a waterfall. Black shales with many thin limestones, some composed almost entirely of *Neomiodon* shells, and layers of 'beef' are exposed at intervals in the stream above the fall.

In an unnamed stream 1000 yd north of Rigg this same leaf of sill, here about 50 ft thick and resting directly on the White Sandstone, causes another waterfall. Above it the '*Estheria*' Shales are exposed in the burn for about 500 yd. Two dykes cross this section and 150 yd to the south of the more westerly dyke about 10 ft of indurated '*Estheria*' Shales crop out below a higher leaf of the sill.

From here northwards the shales are covered by peat and boulder clay as far as the section in the Lealt River, already described.

Between Inver Tote and Port Earlish the sediments are dislocated by a plexus of faults, none with a very large throw, but sufficient to cause considerable irregularity in the outcrop. The only section of the beds lying above the sill is that seen in Lonfearn Burn but it is difficult to interpret:

Section in Lonfearn Burn

		ft	in
'*Estheria*' Shales:	Thin hard platy shales (indurated) 70 yds upstream from waterfall	10	0
	Olivine-dolerite sill		
	Fault		
Concretionary Sandstones:	Well-bedded sandstones	about 12	0
	Soft sandstone with doggers	about 10	0
	Platy sandstone	10	0
	Gap in section		
	Calcareous sandstone and sandy shale	5	0
'*Estheria*' Shales:	Black shales	5	0
	Sandy *Neomiodon* limestone	1	6
	Calcareous sandstone	3	6
	Limestone and shales	2	6
	Black paper shales	4	0
	Shale with hard grey *Neomiodon* limestone	5	0
	Black paper shales	4	3
	Hard grey limestone		6
	Hard *Neomiodon* limestone and thin shales	2	0
	Black paper shales	5	0
	Hard limestone		1 in to 2
	Black paper shales	3	0
	Dolerite sills	about 6	0
	Neomiodon shales and shell beds	5	0
	Grey shales	5	0
	Sandy *Neomiodon* limestone		2 in to 10
	Grey shales	3	0

The '*Estheria*' Shales disappear below sea-level just north of the Sgeir Gharbh and are not seen again in N. Trotternish.

The only other locality in N. Skye where the '*Estheria*' Shales are exposed is in the extreme west of Duirinish in the promontory lying between Oisgill Bay and Moonen Bay.

The shales are found in a faulted block which makes a platform roughly square in outline, sloping gently to the east and known as Mointeach nan Tarbh. At its south-west corner the long narrow promontory of Eist juts out to sea, on the east a shallow basin contains Loch Mor and lies at the foot of a lava scrap which rises to over 900 ft. On the south side the bay Camas nan Sithean lies between the promontory of Eist and Waterstein Head.

At the north-west in Oisgill Burn for some 300 yd upstream from the mouth about 60 ft of black shales are exposed. On the beach they can be seen resting on a leaf of sill and are indurated by it. Southwards the sediments are concealed by scree as far as Eist Fhiadhaich (Oisgill Bay). Here about 40 ft of dark grey shale with lighter calcareous bands is seen resting on sill. Southwards there is some small scale faulting and then the sill rises steeply into a high sharp rib (Fig. 14). South of this again is a patch of about 25 ft of yellow, grey and dark limy shales lying almost horizontally against the plunging sill. On the eastern side of the promontory up to 40 ft of dark calcareous shales with thin bands of very fossiliferous *Neomiodon* limestone and occasional sandy beds also containing *Neomiodon*, lie between two sills and are exposed for about 400 yd before the sills come together and pinch out the sediments. Some 250 yd to the east the shales again appear resting on sill. They include several thin sills and are dipping south-eastwards, finally disappearing below sea-level a little beyond An Stac at the foot of Waterstein Head.

Inland and due north of An Stac fragments of the Lower '*Ostrea*' Beds are found scattered in the landslip below the lava scarp. The base of the lavas at Waterstein Head is estimated to be at about 350 ft above sea-level so that there is ample room for a full development of the Concretionary Sandstones and the Lower '*Ostrea*' Beds above the '*Estheria*' Shales at this locality.

The abrupt transgressions of the lower leaf of the sill cause remarkable contortions in the '*Estheria*' Shales. These can be seen very well on the west side of the Eist promontory immediately to the south of the 'rib' of sill and also against a transgression of the sill on the east side also under the cliff of Mointeach nan Tarbh (Fig. 14, p. 130).

CONCRETIONARY SANDSTONES

The Concretionary Sandstones are made up of five repetitions of the cycle, shales and limestones below, sandstone with doggers above. This sequence of cycles can be traced over the whole area though the composition of each unit may vary considerably in detail. *Neomiodon* and *Viviparus*, often very abundant, are virtually the only fossils found in this subdivision.

The most southerly section of the Concretionary Sandstones is that in Lon Druiseach 2½ miles N.N.E. of Portree, where however, only the lower beds are exposed:

Section in Lon Druiseach

	ft	in
Cycle 2		
12. Soft sandstone with calcareous bands	14	0
Gap of 15 ft		
11. *Neomiodon* limestone		8
10. *Neomiodon* shale	2	6
9. Sandy limestone with *Neomiodon*	3	0

Cycle 1	ft	in
8. Calcareous grit with *Neomiodon*	1	4
7. Soft sandstone with calcareous bands and doggers	6	0
6. Hard calcareous sandstone with *Neomiodon*	2	6
5. Grey shale	1	0
4. Soft shaly sandstone	6	0
3. Grey shale	2	0
2. Sandy *Neomiodon* limestone	1	0
1. Sandy shale with *Neomiodon*	1	6

Eastwards the upper beds of this section are cut out by the overlap of the lavas so that in a small gully on the south side of Lon Druiseach the base of the Tertiary rests on bed 9 of the above section and in the sea-cliff, on bed 8.

In the area ½-mile west of Sithean Bhealaich Chumhaing and 1½-2½ miles north of Portree along the Portree-Staffin road are thin bands of sediments enclosed in a dolerite sill. A small exposure in Lon a'Ghlinne, 450 yd east of the road shows sill resting on about 8 ft of soft grey sandstone. Where this band of sediment crosses Lon an t-Sithein 500 yd further north, about 8 ft of soft sandstones and *Neomiodon* limestone are exposed. A second band of sediment crops out 500 yd north of Lon a'Ghlinne and 150 yd east of the road. The section here is:

	ft	in
Sill—very irregular and including fragments of a coarse gritty *Neomiodon* limestone.		
6. Pale carbonaceous sandstone with doggers in uppermost 3 ft	13	4
5. Shale, black and sandy	1	4
4. Hard calcareous band		2
3. Shale, black and sandy		4
2. Hard calcareous band		2
1. Shale, black and sandy	2	2

West of the road and below the lava scarp the abundance of fragments of Jurassic sediments indicates the presence of other sedimentary bands in the sill. The whole of this area forms a long triangular segment bounded by faults which throw down the beds on all sides. These sediments are certainly part of the Concretionary Sandstones and most probably belong to one of the lower cycles.

In the sea-cliff between Craig Ulatota and Fuirnean occasional exposures of sandstone and *Neomiodon* limestones indicate the course of the Concretionary Sandstones outcrop. Inland, both east and west of Loch Fada and for a third of a mile to the south there are numerous small exposures of the Sandstones. In a small stream entering the loch from the east a section showing dark limestones and shales and probably at the top of the '*Estheria*' Shales gives an approximate position for the base of the Concretionary Sandstones.

Outcrops of the Lower '*Ostrea*' Beds just west of the road and loch mark the top of the Sandstones which is seen in small exposures of sandstones and shales on the western shore of the loch. North of Loch Fada the Concretionary Sandstones are obscured by peat and drift but the base must follow closely the western shore of Loch Leathan whilst the Lower '*Ostrea*' Beds above are seen at intervals about 500 yd west of the loch.

The most extensive of these sections is that exposed in Lon Coire na h'Airidh:

	ft	in
7. Platy green shaly shell bed; masses of *Neomiodon*	2	0
6. Light grey shale with *Neomiodon*		9
Gap of 4 ft, probably shales		
5. Sandy limestone, abundant *Neomiodon*	2	3

	ft	in
4. Sandy shell bed crowded with *Neomiodon*	1	0
3. Thin white flaggy sandstone	3	6
2. Hard calcareous sandstone	2	0
1. Thin white flaggy sandstone	2	0

The top of this section is about 12 ft below the Lower '*Ostrea*' Beds.

North of Loch Leathan the landslip extends from The Storr to within 200 yd of the cliff top and sections are rare. But 1500 yd N.E. of the Old Man of Storr a *Neomiodon* limestone is exposed in a small stream and 100 yd further west the Lower '*Ostrea*' Beds.

A mile further north sediments belonging to the middle cycles of the Concretionary Sandstones are exposed below a leaf of sill, 160 yd west of the road and 200 yd north of Rigg Burn:

	ft	in
12. Grey shales	1	6
11. *Neomiodon* shell bed		6
10. Dark limestone with *Neomiodon*	2	6
9. Calcareous shale with *Neomiodon*		8
8. Sandy limestone	2	0
7. Grey shales		9
6. *Neomiodon* shell bed		3
5. Sandy, flaggy, limestone	1	5
4. Calcareous shales	1	9
3. Sandy limestone	1	0
2. Shales with *Neomiodon*	1	0
Gap of a few feet		
1. White sandstone with doggers	10	0

A little further north, a roadside quarry, due west of Rigg, shows beds in the lower part of the Concretionary Sandstones:

11. Sandy shales, very sandy at base	4	0
10. Black shale		4
9. Black sandstone with *Neomiodon*	2	3
8. Brown sandstone	6	0
7. White and yellowish-green sandstone	12	0
Dolerite sill		
6. Brown sandstone		8
5. Yellow sandstone		9
Dolerite sill		
4. White shaly sandstone	1	7
3. Yellow shaly sandstone with *Neomiodon*	5	3
2. Limestone crowded with *Neomiodon*		8
1. Brown shales		

The Concretionary Sandstones are not again exposed until the Lealt River where the three lower cycles and part of the fourth are exposed in the stream, from the ford for a distance of about 1000 yd upstream.

Section in the Lealt River

Cycle 5 (*part*)

	ft	in
30. Grey calcareous sandstone	5	0+
Gap of about 35 ft—largely sandstone?		

Cycle 4 (*part*)	ft	in
29. Grey limestone with *Neomiodon*	7	0+
28. Grey sandy limestone	1	4
27. Brown calcareous sandstone	1	6
26. Dark shaly and sandy limestone		9
25. Yellow calcareous sandstone		6
24. Blue sandy limestone		5
23. Green-grey sandy shale with *Neomiodon*	5	0
22. Grey sandy limestone with *Neomiodon*	4	6
Cycle 3		
21. Sandstone with irregular doggers	5	0
20. Green-grey sandy shale with *Neomiodon*	5	0
19. Blue-grey shelly limestone	5	0
18. Grey sandy shales	10	0
17. Limestones with *Neomiodon*	12	0
16. Coarse calcareous grit	1	4
15. Sandy, shelly limestone	1	8
Cycle 2		
14. Soft grey sandstone with doggers, very calcareous in uppermost 3 ft	22	0
13. Thin, blue-grey sandstone	1	10
12. Thin, sandy and shaly beds		10
11. Sandy limestone with *Neomiodon*		6
10. Soft, green-grey sandstone		11
9. *Neomiodon* shales and limestones with a very rich 4-in shell bed near the middle and a bed full of *Viviparus* (*Bathonella*) at the base	13	0
Cycle 1		
8. Green-grey, shaly sandstone	2	0
7. Dark shale		8
6. Green-grey, shaly sandstone		8
5. Hard grey limestone		1
4. Soft sandstone with doggers, very irregular	3 ft to 6	0
3. Grey, sandy clay	4	8
2. Green-grey, sandy clay	3	0
Gap of about 20 ft (*?sandstone*)		
1. *Neomiodon* limestone ('*Estheria*' shales)		9+

North of the Lealt River the Concretionary Sandstones are to be seen in several fragmentary exposures beneath the Grealin Sill and in the district round Culnaknock and as far north as Loch Mealt but the irregular behaviour of the associated intrusions and extensive faulting in this area make it impossible to identify individual cycles with any certainty. From Port Earlish northwards, however, the Concretionary Sandstones form part of the sea-cliff and extensive sections can be examined in detail. Typical of the sequence hereabouts is that seen at Valtos.

Cliff Section at Valtos

Olivine-dolerite sill	ft	in
Cycle 4		
36. Flaggy sandstones	2	0
35. Hard, massive sandstone	2	0
34. Flaggy sandstones	2	0
33. Hard, massive sandstone	6	0
32. Thin, shaly sandstone		3
31. Soft, yellow sandstone with doggers	2	6

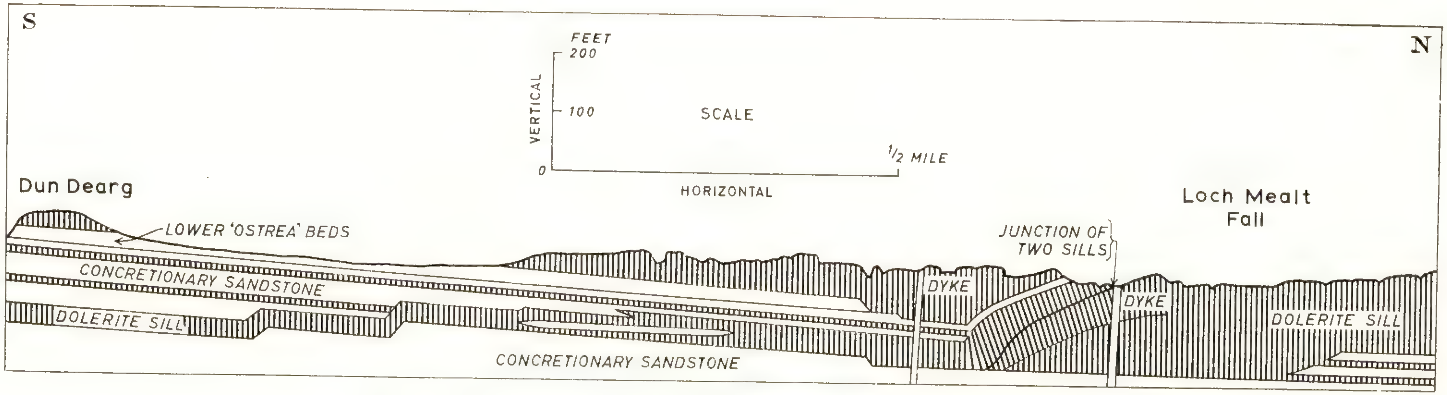


FIG. 7. *Section in sea-cliff between Drum Dearg and Loch Mealt fall*

	ft	in
30. Calcareous sandstone	1	0
29. Thin, shaly sandstones and sandy shales	3	0
28. Shale and *Neomiodon*	7	0
27. Limestone with *Neomiodon*	2	0
26. Shale with *Neomiodon*	7	0
25. Limestone with *Neomiodon*		6
24. Shale with *Neomiodon*		3
Cycle 3		
23. Hard calcareous sandstone	3	0
22. Soft, yellow sandstone with doggers	6	0
21. Thin sandstones and shales	4	0
20. Sandstone	1	6
19. Thin, shaly sandstones	2	0
18. Thin, calcareous sandstones	1	6
17. Soft, yellow sandstone with doggers	1	0
16. Thin, calcareous sandstones	2	0
15. Hard sandstone	1	6
14. Thin sandstones and shales	6	0
13. Irregular, sandy limestone with *Neomiodon*	1 ft to 2	6
12. Soft, yellow sandstone with doggers	7	0
11. Soft, grey shales with *Neomiodon*	5	0
10. Limestone with *Neomiodon*	2 ft 8 in to 4	0
9. Sandy shale with *Neomiodon*	4	6
8. Limestone with *Neomiodon*	2	6
7. Sandy shale		6
6. Calcareous sandstone		6
5. Shale with *Neomiodon*	1	0
4. Sandy, grey-green shale	2	0
Cycle 2 (*part*)		
3. Calcareous grit	1 ft to 3	0
2. Soft yellow sandstone with doggers	18	0
1. Hard calcareous sandstone	3	0

At Dun Dearg the later cycles of the Concretionary Sandstones are incorporated in the sea-cliff together with the Lower '*Ostrea*' Beds. The sediments exposed in the cliff between Dun Dearg and the Kilt Rock measured at various points where accessible, are shown in the following section (see Fig. 7).

Strata between Dun Dearg and the Kilt Rock

Dolerite Sill

Concretionary Sandstones

	ft	in
Cycle 5 (*part*)		
44. Calcareous sandstone or sandy limestone	1 ft to 3	0
43. Coarse grained calcareous pebbly grit	1	0
42. Very calcareous sandstone with thin calcareous shales at the base	15	0
41. Soft sandstone with doggers	15	0
40. Sandy shale with thin, sandy limestones	2	0
39. Grey, sandy shale	5	0
38. Hard, sandy limestone	8	0
37. Hard, sandy limestone	4	0
36. Grey shale	5	0
35. Hard, sandy limestone	8	0
34. Grey shales	2 ft to 3	0

Cycle 4	ft	in
33. Thin, flaggy sandstones	2	0
32. Hard, massive sandstone	2	0
31. Thin, flaggy sandstones	2	0
30. Hard, massive sandstone	6	0
29. Thin, shaly sandstones		3
28. Soft, yellow sandstone with doggers	2	6
27. Hard, calcareous sandstone	1	0
26. Thin, sandy and shaly beds	3	0
25. Dark shales with *Neomiodon spp.*	7	0
24. Grey limestone with *Neomiodon*	2	0
23. Dark shales with *Neomiodon*	7	0
22. Grey limestone with *Neomiodon*		6
21. Dark shale with *Neomiodon*		3
Cycle 3		
20. Hard, calcareous sandstone with *Neomiodon*	3	0
19. Soft sandstone with doggers	6	0
18. Thin sandstones and shales	4	0
17. Sandstone	1	6
16. Thin, shaly sandstones	1	0
15. Hard, calcareous sandstone in platy, 3-in concretionary layers with thin partings of shale and in the middle a 1-ft bed of soft sandstone with small doggers	4	0
14. Hard, calcareous sandstone	1	6
13. Thin sandstones and shales	6	0
12. Hard, very irregular, sandy limestone	1 ft to 2	6
11. Soft sandstone with large doggers	7	0
10. Soft grey shales with *Neomiodon*	5	0
9. Hard grey limestone with *Neomiodon* and *Hybodus*	2 ft 8 in to 4	0
8. Sandy shale with *Neomiodon*	4	6
7. Grey limestone with *Neomiodon*	2	6
6. Sandy shale full of worm casts		6
5. Calcareous sandstone, ripple-marked and sun-cracked		6
4. Grey shale with *Neomiodon*	1	0
3. Sandy, grey-green shale with coprolites	2	0
Cycle 2 (*part*)		
2. Calcareous grit	1 ft to 3	0
1. Soft sandstone with doggers	18	0

The best section of the higher beds of the Concretionary Sandstones is seen ¾ mile south of Rubha Garbhaig.

Section in the Cliff ¾ mile S.E. of Rubha Garbhaig

Dolerite sill

Ostracod Limestones	ft	in
46. Yellowish, hard baked marl with crushed *Neomiodon*	2	0
45. Yellow, fine-grained, thin-bedded calcareous sandstone with crushed *Viviparus*, *Neomiodon* and Ostracoda	2	0
44. Yellowish, sandy marl	3	9
43. Very dark brown, greasy clay with *Neomiodon*, '*Euestheria*', and Ostracoda	3	0

Lower 'Ostrea' Beds

		ft	in
42.	Hard grey limestone crowded with *Liostrea hebridica* Forbes	4	0
41.	Black rusty shale with small *Neomiodon spp.*	4	6
40.	Hard grey limestone	1	1
39.	Grey shale crowded with *Liostrea hebridica*	1	5
38.	Hard, grey limestone		11
37.	Grey shale crowded with *Liostrea hebridica*	7	0
36.	Rusty shales with *Neomiodon spp.*	8	0
35.	Dark, shaly sandstone	4	0
34.	Fairly hard, calcareous sandstone	15	0
33.	Hard, calcareous sandstone	2	0
32.	Sandy shale	1	9
31.	Sandy limestone		4
30.	Dark shale with *Liostrea hebridica*		6
29.	Grey limestone with *Liostrea hebridica*		4
28.	Sandy shales	1	6
27.	Pale brown, sandy and pyritous, fragmental shell limestone with *Neomiodon spp.*	1	0
26.	Sandy limestone		8
25.	Sandy shale		9
24.	Rusty shale with *Neomiodon spp.*	3	6
Concretionary Sandstones (Cycle 5)			
23.	Hard, concretionary, calcareous sandstone with doggers attached to base	4	0
22.	Soft, white, fine-grained calcareous sandstone with large doggers	13	0
21.	Hard, calcareous sandstone		4
20.	Soft, white sandstone	2	0
19.	Hard, calcareous sandstone		6
18.	Soft, white sandstone		9
17.	Hard, calcareous sandstone		8
16.	Sandy shale	3	6
15.	Hard, sandy limestone		4
14.	Grey, sandy shale	5	6
13.	Grey, micaceous, calcareous sandstone with *Neomiodon spp.*	2	7
12.	Black shale	2	6
11.	Hard, grey, sandy limestone		8
10.	Black shale	4	0
9.	Light grey, fine-grained, calcareous sandstone	4	3
8.	Bands of dark grey, sandy and shaly limestone and sandy, calcareous shale	1	1
7.	Black paper shales	9	2
6.	Hard, dark grey, impure, sandy and gritty limestone with small greenish patches and bands of *Neomiodon spp.* Current bedded. The basal 2-3 in is marly and weathers fawn colour	4	0
5.	Dark grey, sandy and shelly limestone with *Neomiodon cunninghami* (Forbes)	1	2
4.	Dark grey, fine-grained, shaly and streaky sandstone with some *Neomiodon cunninghami*		10
3.	Dark grey, shaly, fine-grained sandstone with *Neomiodon cunninghami*	1	6
2.	Light grey, calcareous sandstone with abundant *Neomiodon cunninghami*	2	4
1.	Grey, crystalline limestone with numerous shell fragments. Baked by underlying sill	3	0
	Dolerite sill.		

The lowest bed in this section rests on a leaf of sill and is in places partly incorporated in it. The degree of alteration induced by the intrusion varies from place to place. Generally the limestone has become saccharoidal, but in some cases the alteration has gone further and small groups of dark calcite crystals have developed giving the rock a spotted appearance. Pockets in the top of the sill are often filled with masses of black calcite.

The beds 1 to 23 inclusive in the above section represent the uppermost strata of the Concretionary Sandstones. It will be seen that the lower 47 ft consist of shales and sandy limestones with *Neomiodon cunninghami* whilst above is a massive bed of sandstone 21 ft thick with thin calcareous bands and large calcareous doggers. These doggers are hard flattened-spheroidal calcareous concretions ranging from 3 ft to 15 ft in diameter. It is clear that the concretions were formed secondarily *in situ* for the current bedding of the sandstone continues without break through them. The uppermost 4 ft of the sandstone is a hard, concretionary band formed by the growing together of a number of adjacent doggers. On the underside the doggers are to be seen apparently suspended from it and in all stages of emergence. This seems to suggest that the formation of the concretions was penecontemporaneous and that at this level the amount of calcium carbonate available was not enough to allow of the doggers developing sufficiently large to fuse laterally and to form a continuous band as they did immediately above.

In Eigg the division is more sandy and exhibits the phenomena peculiar to these beds even more markedly. The doggers are here very conspicuous features and were described in graphic terms by Hugh Miller (1858, pp. 56-7). As in Skye the quartz grains comprising these sandstones are fairly uniform in size and on weathering give rise to 'musical sands' which are especially well developed in Camas Sgiotaig in Eigg and on the northern shore of Loch Leathan in Skye.

In Strathaird the Concretionary Sandstones are represented by the subdivision 'II (*Cyrena* Limestones)' described as 'massive blue sandy and often crystalline limestones and calcareous sandstones' (Peach and others 1910, p. 121). The thickness is here only 70 ft so that there has been a great reduction in the amount of coarse detrital material between North Trotternish and Strathaird. Apparently the sandstone unit in each sedimentary cycle has thinned out southwards so that at Strathaird only the calcareous-argillaceous unit is left, for if the sandstones be removed from the North Trotternish succession then the remainder of the Concretionary Sandstones approximates in thickness to the *Cyrena* Limestones of Strathaird.

Northwards from the section given above, most of the sediments are hidden by scree but there are small patches of the lowest beds (limestones and shales with *Neomiodon*) to be seen resting on the top of the sill as far as Rubha Garbhaig. Here the beds are thrown down to the north by a N.N.W. fault and the sandstones with doggers form the floor of the small bay between Rubha Garbhaig and Sgeir nam Faoileann. A second fault then throws down the sandstones again to the north after which they are not seen again on the east side of the peninsula.

The ground between Kilt Rock and the section just described, which displays interesting transgressions of two leaves of a sill, is most conveniently described from north to south. Southwards the section is obliterated by scree and rock falls from the overlying sill for about a quarter of a mile, but at the Kilt Rock a good, though less complete exposure of these beds is again visible. Where the sediments again appear to the south of the scree an upward transgression of the lower leaf of the sill has cut out about 10 ft of the limestones and shales at the base of the section and a downward transgression of the upper leaf has cut out the upper shales of the Lower '*Ostrea*' Beds (See Fig. 7). At the Kilt Rock the upper sill again has descended to rest on the lower shales of the Lower '*Ostrea*' Beds, but south of the Kilt Rock rises up again to the old position. About 70 yd south of Cadha an Tuill the upper sill transgresses downwards again and cuts out the whole of the Lower '*Ostrea*' Beds for a distance of 80 yd or so. Farther south it rises again to the middle of the Lower '*Ostrea*' Beds leaving a thin leaf between this group and the Concretionary Sandstones below, whilst the lower sill has dropped 16-17 ft leaving a thin leaf at the old level.

A deep cleft in the cliff one third of a mile south of the Kilt Rock marks the position of a considerable transgression. Here the upper sill moves downwards so as cut out all the sandstone with doggers and some of the shales and limestones below leaving only about 30 ft of sediment between the two main leaves of sill. At this point the succession in the Concretionary Sandstones varies slightly from that of the section to the north. The uppermost part of the sandstone with doggers contains a 1-ft limestone overlain by a conspicupus coarse calcareous grit also 1 ft thick.

Immediately north of the Mealt waterfall the upper and lower leaves of the sill unite and with the exception of a few inches of limestone at sea-level the whole cliff 175 ft high is sill. This transgression at the Mealt fall as indicated by the distribution of the Jurassic rocks inland is actually parallel to the strike of the sediments, i.e. N.N.E., and not parallel to the dip as would appear to be the case from the cliff section. The elucidation of the transgressions of the sills at the Mealt fall is made more difficult by the sudden thickening of the lower leaf about 350 yd south of the fall, and by the fact that the cliff bulges seawards just at the plane of transgression (see Fig. 7) because of its resistance to marine erosion.

About 500 yd south of Mealt fall the section is obscure but the two leaves of the sill appear to separate and the upper leaf transgresses upwards whilst the lower leaf transgresses downwards, leaving at least two thin sills between, one lying near the base of the shales and limestones and the other between the shales and limestones and the overlying sandstone with doggers. Here lower beds appear at the base of the cliff than any seen north of the Mealt fall.

At Rubha Hunish, the extreme north-westerly point of Trotternish there are small exposures of the Concretionary Sandstones. The sediments are enclosed between the sill of Meal Tuath and that forming the promontory of Hunish, but are for the most part covered by scree. At the northern edge of the Meal Tuath scree however, fragments of baked shale and sandstone are to be seen resting on the sill dipping 10° to the south-east, and the following section is exposed on the eastern side of the headland in Lub a'Sgiathain: Thin bedded hard sandstone 1 ft; Soft sandstone with doggers 15 ft; on Thin argillaceous sandstones with *Viviparus scoticus* (Tate) 2 ft.

These beds are cut off on the seaward side by a N.W. fault which throws down to the east and the cementstone exposed on the beach near low tide mark at about the same level as Bed 1 of the above section belongs to the Ostracod Limestones (see p. 46.)

The Concretionary Sandstones are again exposed in Lub Score south of Duntulm. Soft sandstones with doggers appear from below the Lower '*Ostrea*' Beds at a point [402727] on the coast. About 10 ft of sandstone are exposed in two small cliffs associated in the southerly one with ostracod marls, and small patches of sandstone with doggers, hard calcareous sandstones and sandy limestones are to be seen in the beach for the next 600 yd to the south after which they disappear below sea-level.

A small N.W. fault at Osmigarry throws down to the N.E. so that the calcareous sandstones are again seen in a small exposure [392720] on the beach before being finally covered by the Lower '*Ostrea*' Beds. This series is not again exposed on the west coast of North Trotternish.

In Vaternish and Duirinish there are no extensive sections in the Concretionary Sandstones. On the western shore of Loch Snizort is an area of landslip, Score Horan, which conceals an outcrop of Jurassic rocks which, from fragments seen in the landslip, must belong to this subdivision, and on the shore of Loch Losait, a bay cut in the northern side of the slipped mass, is a small exposure of brown sandstone, 200 yd west of which is a knob of dolerite sill. Eastwards, loose fragments of sandstone and *Neomiodon* limestone can be found on the beach and at the promontory of Oans is another outcrop of sill. Here sediments are brought above sea-level by a small anticline and along the axis at Biod a'Ghoill there is room for at least 300 ft of sediments below the lavas.

It is probable that the same subdivisions of the Great Estuarine Series are present here as in Loch Bay i.e. Ostracod Limestones, Lower '*Ostrea*' Beds and Concretionary Sandstones.

On the west coast of Vaternish the Concretionary Sandstones probably crop out in Ardmore Bay. At Trumpan the base of the lavas is seen resting on Palagonite Tuffs which are dipping to the north-east at 8° and are in turn underlain by a dolerite sill containing a lenticle of grey shale. Approaching Ard Beag the sill turns over to the west at an angle of 45° and appears to be faulted against the lava crags of Ard Beag. Though no sediments are exposed above sea-level in Ardmore Bay the beach is strewn with boulders of *Neomiodon* limestone, fragments of an '*Ostrea*' bed and large doggers.

Further south a sandy *Neomiodon* limestone is exposed at beach level on the western shore of Clett, dipping W.S.W. at 6° and probably belongs to the Concretionary Sandstones. The limestone is in two leaves separated by a one-inch layer of 'beef', the lower is a *Neomiodon* shell-bed one-foot thick, the upper, two-feet thick, directly underlies dolerite sill. The lower portion of the sediments (see p. 42) exposed on Mingay, i.e. the white sandstone and *Neomiodon* limestone may also be part of the Concretionary Sandstones.

In Loch Bay the uppermost portion of the Concretionary Sandstones is exposed. The most complete section is that in a small cliff just north of Cnoc na Cairidh:

Lower 'Ostrea' Beds	ft	in
14. Grey shales	4	0
13. Black shale		4
12. Brown and purple sandstone with casts of *Neomiodon*, calcified in part	2	0
11. Soft, white sandstone	2	9
10. Grey, sandy shales	2	0
9. Soft, white sandstone	about 4	0
8. Sandy *Neomiodon* limestone	1	6
7. Soft, white sandstone	5	0
6. Grey *Neomiodon* limestone	2	6
5. Soft, grey, carbonaceous sandstone	1	6
4. Calcareous and carbonaceous sandstone	1	3
3. Sandy *Neomiodon* limestone	3	0+
2. Black *Neomiodon* shale	3	0
Dolerite sill, 12 ft, but thinning southwards		
1. *Neomiodon* shales and limestones		

The most westerly occurrence of the Concretionary Sandstones is that concealed beneath the landslip between Waterstein Head and Loch Mor in Duirinish.

The occurrence of landslip at Geodh' an Tairbh, Dunvegan Head suggests that sediments crop out below the lavas but no trace of them has been detected.

Judd (1878, p. 724) stated that strata belonging to the Great Estuarine Series are to be seen beneath the lavas at "Copnahow Head" (Gob na Hoe) and showed the outcrop on his map (fig. 1). In this area, however, the base of the lavas is below sea-level and no other observer has recorded sediments in the neighbourhood of Hoe Point. As Judd's map does not show the sediments at Eist it is possible that he confused the two headlands. Bryce (1837) in his Map of the Islands of Skye and Raasay shows the outcrop correctly (fig. 1).

LOWER 'OSTREA' BEDS

The Lower '*Ostrea*' Beds comprise a complete sedimentary cycle of the type seen in the Concretionary Sandstones, i.e. shales and limestone below, sandstones above, and the shale phase of a higher cycle, the sandstone portion of which is the lower half of the Ostracod Limestones.

The most complete sequence in this subdivision is seen in the section ¾ mile south of Rubha Garbhaig (p. 32), where the characteristic three subdivisions are well seen:

3. Soft shales and muddy limestones often crowded with *Liostrea hebridica*	about 35 ft
2. Sandstone	about 17 ft
1. Soft shales and thin limestones with *Liostrea hebridica*	about 10 ft

The upper shale-limestone group includes, about 15 ft from the top, an algal limestone which has been traced throughout Skye (Anderson 1948), and even further afield (Hudson 1963).

It consists of angular fragments of dark limestone originally a layer built up by the confluent growths of the alga *Cayeuxia nodosa* Anderson, but penecontemporaneously brecciated and re-cemented. The algal nodules are grey-blue in colour with a porcellaneous texture, and weather creamy white. Other fossils in the Lower '*Ostrea*' Beds consist mainly of *Liostrea hebridica* (Forbes) and *Neomiodon spp.* But Rhynchonellids, *Kallirhynchia concinna* (J. de C. Sowerby), are found in these beds at Duntulm, and Tate (*in* Bryce 1873) records a number of gastropod and lamellibranch species from Loch Bay, some of which are undoubtedly marine forms.

In addition to the common *L. hebridica*, Anderson and Cox (1948) recorded the following species from the Lower '*Ostrea*' Beds of Skye: *Pleuromya robusta* (Tate), *Corbula hebridica* Tate, *Neridomus arata* (Tate), *Viviparus scoticus* (Tate), *Zebina caledonica* (Tate), to which Hudson (1963) has added: *Cuspidaria ibbetsoni*, *Placunopsis socialis*, *Anisocardia* (*Antiquicyprina*) *cucullata* (Tate), *Quenstedtia forbesi* Anderson and Cox, *Myopholas acuticostata* (J. de C. Sowerby) and *Globularia formosa?* (Morris and Lycett).

The shells of *Liostrea hebridica* are at times so plentiful that there are beds from 7 to 10 ft thick almost entirely composed of them.

The Lower '*Ostrea*' Beds represent a widespread brackish-marine phase and wherever the Concretionary Sandstones are exposed these '*Ostrea*' beds are seen to overlie them. They are present in Trotternish, Vaternish and Duirinish in North Skye, in Strathaird and Strollamus in South Skye, and in Eigg, Muck and Raasay. There is no palaeontological evidence that these '*Ostrea*' beds are contemporaneous for *Liostrea hebridica* occurs from top to bottom of the Great Estuarine Series. They do indicate however the occurrence of a tectonic disturbance which affected a wide area and resulted in a marine-estuarine phase lying between freshwater-estuarine beds. The absence of diagnostic zone fossils is a common feature of estuarine and freshwater deposits so that palaeontological zoning is rarely possible. Furthermore in shallow water deposits of this nature rapid lateral lithological changes are the rule. The only method of correlation left is the recognition of tectonic movements which have caused a widespread change in the sedimentation of the area. Shallow water deposits are particularly sensitive to small changes of level so that even minor movements may be often easily recognized. In the Hebridean area correlation by the comparison of sedimentary rhythms is especially valuable in the Great Estuarine Series, for as the name implies, the whole series was deposited in a large estuary in which facies changes were rapid and in which more or less the same fauna lived throughout the period.

In Trotternish the most southerly exposure of the Lower '*Ostrea*' Beds lies a few yards west of the road and 100 yd south of the southern end of Loch Fada, where 2 ft of calcareous sandstone and 2 ft of sandy *Neomiodon* limestone are exposed. The following section can be seen 120 yd north of this exposure:

	ft	in
Dolerite sill		
7. Dark shale	1	0
6. Limestone with scattered *Liostrea hebridica*	1	0
5. Dark, brecciated algal limestone		4
4. Shale with algal nodules	1	0¼
3. Thin limestone		1
2. Soft, brown shale	1	0
1. Shale crowded with *Liostrea hebridica*	9	0

Further north, 3 ft of indurated limestone with *L. hebridica* are exposed 100 yd south of Lon Coire na h-Airidh, and in the next burn north, fragments of a white '*Ostrea*' limestone indicate the presence of an unexposed outcrop of the Lower '*Ostrea*' Beds. This white limestone is seen *in situ* 650 yd further north in a gully west of the road. The section here is:

	ft	in
Dolerite sill		
11. Sandy limestone	1	0
10. White limestone crowded with *L. hebridica*	4	0
9. Limestone with *Neomiodon*	2	0+
8. Black shale		6+
7. Hard, grey limestone		6
6. Dark grey shale	4	0
5. Light, grey marl	2	0
4. Massive sandstone	3	0
3. Platy sandstone	4	0
Gap of 5 ft		
2. Shaly, brown sandstone	1	0+
Gap of 6 ft		
1. Calcareous and carbonaceous sandstone	1	0+

North of this section '*Ostrea*' beds are exposed at intervals for the next 300 yd and again west of the middle of Loch Leathan just before the Lower '*Ostrea*' Beds disappear beneath the landslip to the north.

At Tottrome at the head of the most southerly of the two streams and 1100 yd 15° N. of E. of the Old Man of Storr the Lower '*Ostrea*' Beds are exposed as follows:

	ft	in
7. White limestone crowded with *L. hebridica*	3	0+
6. Black, shaly limestone with *L. hebridica*	6	0
5. White limestone with *L. hebridica*	3	0
4. Soft, calcareous sandstone with *Neomiodon* and *L. hebridica*	6	0
Gap of 6 ft		
3. Yellow sandstone	7	0
Gap of 14 ft		
2. Sandy *Neomiodon* limestone	3	0
1. White calcareous sandstone	3	0

The '*Ostrea*' Beds can be traced southwards for about 100 yd from the stream.

The difference in detail between this section and that west of Loch Fada emphasizes the rapid lateral change in lithology which is so characteristic of the sediments of the Great Estuarine Series.

North of the southern tributary of the most northerly stream at Tottrome 6 ft of '*Ostrea*' limestone are exposed, Northwards the Lower '*Ostrea*' Beds are covered by thick peat but the course of the overlying sill can be traced for the next three miles or so, until at Dun Connavern they are displaced by a downward transgression of the sill.

In the small bay west of Sgeir nam Faoileann about 20 ft of the Lower '*Ostrea*' Beds are exposed but are disturbed and baked by irregular sills. The same beds are again seen in the jetty at Ob nan Ron where a few feet of baked limestone are exposed above and below a thin leaf of sill. North-westwards a section of the Lower '*Ostrea*' Beds occurs along the beach from Ob nan Ron to An Corran, at the southern end of which they overlie 18 ft of sandstone and at the northern end contain abundant *Liostrea hebridica* with *Myopholas acuticostata* (J. de C. Sowerby) and *Neomiodon sp.* Associated with the '*Ostrea*' beds at this locality is the algal bed seen further south.

Two small exposures on Staffin Island are of beds belonging to this group. At the south-western corner 18 ft of sandstones, limestones and shales containing masses of *L. hebridica*, *Neomiodon spp.*, *Corbula hebridica* Tate, *Myopholas acuticostata* and *Trigonia sp.* are seen on the beach below the fisherman's hut, and a small patch of indurated limestone with *Neomiodon spp.* rests on the sill in the small inlet west of Rubha Ban.

South of the type section (p. 32) the upper third of the Lower '*Ostrea*' Beds is displaced from the cliff section by a downward transgression of the overlying sill. A further transgression displaces the middle sandstone at Cadha an Tuill and south of the Mealt waterfall the Lower '*Ostrea*' Beds are completely displaced so that from here to Dun Dearg the upper sill rests on the Concretionary Sandstones (see Fig. 7, p. 30).

In the area round Loch Mealt the sill is denuded almost to the base so that in the angles of the transgressive portions the sediments below the sill are very near the surface. Consequently any deep section tends to cut right through the sill and expose the Jurassic strata below. In the Kilmartin River due west of Elishader is a small exposure in the east bank showing three to four feet of the Lower '*Ostrea*' Beds, shales and thin limestone with *Liostrea hebridica.* Baked shales belonging to the same group of beds form part of the small knoll 300 yd to the east. The strata exposed in these two sections belong to the upper shales of the Lower '*Ostrea*' Beds.

The middle sandstone of the Lower '*Ostrea*' Beds is seen below the sill in two small quarries at the north-west corner of Loch Mealt about 150 yd from the Loch, and again in a small quarry alongside the Marishader road about 250 yd south-east of the bridge over Kilmartin River. The lower shales of the Lower '*Ostrea*' Beds are exposed in small sections round Loch Mealt in Elishader, Raisaburgh and on the shore of the loch north and south of the small promontory in the south-east corner of the loch.

Lower '*Ostrea*' Beds are again exposed on the west and north sides of Port Gobhlaig, Kilmaluag Bay. A section on the beach and in a low cliff shows the following sequence:

Section at Port Gobhlaig, Kilmaluag

	ft	in
Ostracod Limestones		
20. Sandy limestone	1	0
19. Black shale		1½
18. Pale grey cementstone		4
17. Shelly and sandy limestone	1	0
16. Soft sandstone	2	0
Strata not exposed	8	0
15. Black shale	3	0
14. Pale grey marl with Ostracods and *Hydrobia praecursor* Sandberger	1	0
13. Sandy shale	4	0
Strata not exposed for a few feet		
Lower 'Ostrea' Beds		
12. Algal Band	1	3
11. Dark shales with *L. hebridica;* a thin '*Ostrea*' limestone near the middle	6	0

	ft	in
10. Pale grey cementstone		3
9. Marly shale with *Neomiodon*		0½
8. Hard grey marl		1
7. Sandy shale with *Neomiodon*	?	
Strata not exposed for a few feet		
6. Indurated limestone	1	0
5. Indurated shale with *L. hebridica*	3	0
Dolerite sill, 4 ft at the cliff and thinning to 1 ft seawards		
4. Indurated shale with *L. hebridica*	3	0
Thin dolerite sill, 1 ft		
3. Indurated shale	2	0
2. Indurated shale with *L. hebridica*	2 ft to 3	0
1. Indurated shale with *Neomiodon spp.* and *Myopholas acuticostata*	2	0
Dolerite sill		

Two inclusions of baked limestone and shale in sill on the foreshore just west of Rubh' Bheanachain (Ru Vannarain) on the north side of Kilmaluag Bay may represent part of the Lower '*Ostrea*' Beds but are highly altered.

Numerous small exposures in the valley of Kilmaluag River south of the main road indicate a horizon very like that of the beds in Port Gobhlaig. In the bed of this stream 50 yd south of the road is a highly fossiliferous limestone, 2-3 ft thick, containing masses of *Neomiodon brycei* (Tate), and small patches of shale are exposed at the sides of the roads which run along the top of either bank. For some 400 yd south of the road the river runs in a narrow gorge and then for a third of a mile over a wide flat of Mottled Clays.

In a small cliff on the west bank of the stream opposite Connista the following section is seen in three successive exposures: Baked marls 3 ft; Gap of a few feet; Soft, white sandstone 6 ft, on Sandy shale 5 ft.

On the same side of the river, 200 yd south of this section, are a number of small exposures of irony, paper shales high up in the bank, whilst opposite a small cliff at a bend in the stream, shows about 5 ft of sandy shales and dark paper shales with abundant *Neomiodon spp.* A little to the south a small tributary enters the river with an exposure of rusty shales in the east bank near Point 197 [433727], and 800 yd further westwards grey shales and marls are exposed in the banks of the main stream.

These fragmentary exposures in the Kilmaluag River are clearly non-continuous masses of rock caught up in the sill and probably indicate that the river bed is not far above the base of the sill.

The Lower '*Ostrea*' Beds are well exposed south of Duntulm in Cairidh Ghlumaig. Here the general dip is easterly but the beds are disturbed by numerous dykes and irregular tongues of sill. The only continuous section of any great extent is in the north-east corner of the bay 500 yd S.S.E. of Duntulm Castle seen on the beach for about 200 yd and in a small cliff.

Section in the beach, Cairidh Ghlumaig, Duntulm

Lower 'Ostrea' Beds	ft	in
29. Dark shales with *L. hebridica*	3	0
28. Dark shales with fragments of *Liostrea* and *Myopholas*	1	0
27. Hard limestone with *L. hebridica*	1	0
26. Dark shales with *L. hebridica*	1	0
25. Hard, fawn-coloured shelly limestone with *Neomiodon spp.*	1	4
24. Grey, sandy shale with *Neomiodon*		5
23. Brecciated, grey-brown algal limestone		6

		ft	in
22.	Dark grey, laminated shale		1½
21.	Irregular sheet of thin agal limestone		1
20.	Grey, sandy limestone		3
19.	Irregular beds of sandy, grey, calcareous shales with platy layers at the base	2	6
18.	Grey limestone with *L. hebridica*		9
17.	Sandy and argillaceous limestone with *L. hebridica*		5
16.	Sandy grey shale with *Kallirhynchia concinna, Myopholas acuticostata L. hebridica* and *Trapezium sp.*	2	0
15.	Sandy and argillaceous, grey limestone with *Neomiodon cunninghami, Corbula hebridica, Myopholas acuticostata, Kallirhynchia concinna, L. hebridica* etc.		6
14.	Hard, grey limestone		6
13.	Dark grey, sandy shale		1½
12.	Dark brown, sandy and argillaceous limestone	1	7
11.	Black, sandy shale with thin sandstone ribs, *L. hebridica*		8
10.	Dark sandy and argillaceous limestone		11
9.	Hard, grey-brown, sandy limestone		2
8.	Dark sandy and argillaceous limestone		10
7.	Black, sandy shale		10
6.	Hard, grey limestone	1	0
5.	Slightly indurated, black shales	1	0
4.	White sandstone	1	0
3.	Indurated, pale grey, sandy shale	1	6
	Dolerite sill	17	0
2.	Hard, grey, sandy limestone		6
1.	Grey, sandy shale	2	0

A small cliff in the north-east angle of the bay is made up of beds 15-29 of the above section. Here the *Rhynchonella* beds (15-16) are more fossiliferous than in the beach, and the algal limestone (23) is more easily recognized. There is also an additional algal bed in the form of a thin layer 1 in thick on the top of bed 25.

The Lower '*Ostrea*' Beds exposed in Cairidh Ghlumaig represent only the lower part of this group (i.e. beds 24-30 of the Rubha Garbhaig section, p. 33) but show a much greater development than on the east coast. The abundance of such forms as *Kallirhynchia* and *Myopholas* show also that the beds were laid down under more marine condtitions.

From here southwards as far as Lon Onstatoin, the stream just S. of Bealach lochdarach, patches of the Lower '*Ostrea*' Beds are exposed between tide marks, and the main road cuts through a thick '*Ostrea*' bed 600 yd north-east of the bridge over this stream. The section seen in the banks of Lon Onstatoin continues the sequence upwards from the topmost bed of the Cairidh Ghlumaig section:

Section in Lon Onstatoin

Dolerite sill

Ostracod Limestones		ft	in
17.	Baked, cream-coloured mudstone	1	2
16.	White and glauconitic sandstones with casts of *Viviparus*	1	1
15.	Indurated, black shales	3	6
14.	Pale yellow, marly sandstone	1	4
13.	Iron-stained, blocky shales	5	0
	No exposure. Flat marshy ground	60 ft to 70	0
	No exposure. Probably sill. Gorge in stream	20	0

Lower 'Ostrea' Beds	ft	in
12. Iron-stained, blocky shales	2	0
11. Dark shales with *L. hebridica*		10
10. Grey limestone with *L. hebridica*		9
9. Thin, calcareous shales		5
8. Pale grey cementstone with *Liostrea*		3
7. Papery shales with *Neomiodon spp.*	3	10
6. Blocky, grey shale with *Neomiodon spp,*	3	0
5. Soft, yellow sandstone with shaly bands, abundant *Neomiodon* and *Viviparus*	2	3
Strata not exposed	18	0
4. Grey limestone with *Liostrea*	3	0
3. Dark shale with *Liostrea*	3	0
2. Grey limestone with *Liostrea*		4
1. Dark shale with *Liostrea*	3	6

In a bluff on the east side of the road, 750 yd S.W. of Lon Onstatoin soft, pale brown sandstones are exposed to a depth of 50 ft. They are penetrated throughout by thin veins and irregular nodules of highly decomposed dolerite and rest on 6 ft of indurated shales and limestones with *Neomiodon*, which are underlain by dolerite sill. This sill and the overlying beds probably occupy the gap in the Lon Onstatoin section between the beds 12 and 13. At Peingown the sandstones are again seen in a cutting on the north-east side of the road, south-east from Flora Macdonald's Monument. At the east end of this section the 50-ft sandstone is exposed for about 300 yd; at the west end a series of small step faults drop down the beds to the west and marls and shales overlying the sandstones are exposed as far as the ruined chapel. The general dip here is easterly.

These sections again indicate a considerable increase in the thickness of the Lower '*Ostrea*' Beds as compared with the east coast. The lower series comprising *Liostrea* and *Neomiodon* shales is here about 45 ft thick as compared with a thickness of 10 ft for the corresponding beds in the Rubha Garbhaig section (p. 33), and the middle sandstone is here 50 ft thick as compared with a thickness of 17 ft in the east.

From Peingown the sandstone scarp swings round to the south-west and can be traced to Heribusta and for a short distance beyond until the beds are truncated by the north-west fault which runs out to sea at Osmigarry.

A few yards south-west of the mouth of Lon Onstatoin the lowest beds of the Lower '*Ostrea*' Beds are exposed on the beach overlying the Concretionary Sandstones. At Osmigarry the beds are thrown down to the south-west by a small fault and small outcrops of the Lower '*Ostrea*' Beds again appear at intervals on the beach between here and Lon Sgapail. On the north-east side of the mouth of Lon Sgapail a fault, at this point occupied by a large dyke, throws down the strata to the south-west and brings Lower '*Ostrea*' Beds against the Ostracod Limestones. This fault runs in a south-south-easterly direction through Hunglader and brings the Heribusta sill on its eastern side against Ostracod limestones and higher beds on the west.

The Lower '*Ostrea*' Beds are not seen again on the west coast of North Trotternish except for a lenticle caught up in sill 300 yd W. of Gairbh-sgeir and exposed in the sea-cliff near high-water mark showing a band a little over 6 ft thick composed of black shale, marl and sandstone with *Neomiodon*, which extends for several hundred yards enclosed between two leaves of sill; and for a small exposure of about 6 ft of '*Ostrea*' and *Neomiodon* shales below the leaf of sill which forms Sgeir Lang and on the east side of the jetty. The dip here is south-west at about 5°.

In Vaternish, Lower '*Ostrea*' Beds probably crop out though not exposed in Score Horan and Ardmore Bay.

On the east coast of Mingay about 25 ft of sediments are visible below the sill which forms most of the island. They include 5 ft of '*Ostrea*' shales together with a white sandstone and a *Neomiodon* limestone dipping about 7°, a few degrees south of west. The limestone was once worked for lime and the old kiln still stands. On the beach at Stein boulders of '*Ostrea*' limestone are common and indicate an undisclosed, probably submarine, exposure of this bed. The strata at sea-level here appear to belong to the basal part of the Ostracod Limestones.

At the southern end of Loch Bay, Lower '*Ostrea*' Beds are to be seen resting on the Concretionary Sandstones in the lower reaches of the Bay River and at Slochd Mor. From the confluence to the first bend in Allt an t-Sluic Mhoir shaly '*Ostrea*' beds are exposed in the stream bed and in the west bank round the first bend as far as the second. Beyond the second bend a clear section in the east bank shows the upper calcareous-argillaceous phase of the Lower '*Ostrea*' Beds resting on part of the middle arenaceous beds. Just before reaching the third bend the beds are cut by a dyke, alongside the south side of which is a white sandstone overlain by a grey sandstone, both tufa-covered. A few feet of indurated '*Ostrea*' bed adhere to the north side of the dyke. Between this dyke and a waterfall high up on the south bank of the stream is an outcrop of '*Ostrea*' limestone overlain by the *Cayeuxia nodosa* algal band. Just west of the confluence at Slochd Mor in the north bank of the Bay River, '*Ostrea*' beds are exposed dipping S.S.W. and again, just west of the stepping stones in the north bank near the mouth of the Bay River, here dipping S.W. at 30°.

Tate (*in* Bryce 1873, pp. 346-7) recorded the following fossils from Loch Bay, almost certainly collected from the Lower '*Ostrea*' Beds. The names have been revised by Anderson and Cox (1948) and by Casey (1952, 1956): *Anisocardia* (*Antiquicyprina*) *cucullata* (Tate), *Corbula hebridica* Tate, *Liostrea hebridica* (Forbes), *Neomiodon brycei* (Tate), *Pleuromya robusta* (Tate), *Viviparus* (*Bathonella*) *scoticus* (Tate), *Globularia hebridica* Anderson and Cox, '*Leptoxis trochiformis*' Tate and *Neridomus arata* (Tate), *Zebina caledonica* (Tate).

In Lovaig Bay the shore is strewn with boulders of '*Ostrea*' limestone and though the bed was only found *in situ* in one small exposure near the centre of the bay there is little doubt that the Lower '*Ostrea*' Beds crop out beneath the landslip in the eastern part of the bay. Similarly, the fragments of '*Ostrea*' limestone in the landslip at Waterstein Head must indicate the presence of a hidden outcrop.

OSTRACOD LIMESTONES

The Ostracod Limestones in North Trotternish consist chiefly of dark calcareous shales with thin impure limestones, light coloured cementstones and thin sandstones. The total thickness of these beds must be about 90 ft, but there is no complete section exposed and wherever seen the strata are invariably disturbed and often altered by intrusive dolerite sheets. Fossils are rare, the cementstones and marls contain ostracods, the limestones and calcareous shales in places contain *Euestheria murchisonae* and *Viviparus scoticus* is locally found in the sandstones. *Hydrobia praecursor* Sandberger was recorded by Cox (1950), *Assimea skyensis* Anderson and Cox by Anderson and Cox (1948) and *Quenstedtia staffinensis* Anderson and Cox by Hudson (1963), but these are uncommon.

A rough subdivision of this group can be made as the lower half contains most of the sandstones whereas mudstones and limestones are more common in the upper half. The succession of these beds indicates the gradual establishment of quiet lagoonal conditions following the marine-estuarine episode represented by the Lower '*Ostrea*' Beds.

In Strathaird the Ostracod Limestones are described as 'Group IV. Black and blue shales and mudstones with occasional thin limestones', and 'Group V. (Paludina-scotica limestones) Blue, fine-grained smooth argillaceous limestones or cementstones, weathering cream-coloured, containing gasteropods and alternate with shales, fibrous carbonate of lime ('beef'), and thin beds of calcareous sandstone' (Peach and others 1910, p. 121). These two groups together comprise 77 ft of strata which do not differ essentially from the corresponding beds in the north of Skye.

The most extensive section in the Ostracod Limestones is to be seen in that stretch of the Kilmartin River which lies between the road bridge at Stenscholl and the sea. Here the highest leaf of the dolerite sill occupies its most usual position i.e. near the base of the Ostracod Limestones, so that the strata are broken, altered and injected by offshoots from the sill. As the bed of the Kilmartin River is only a little way above the top of the sill the section is much disturbed and difficult to interpret. So far as could be determined the succession is as follows:

Section in Kilmartin River from the Staffin-Portree Road bridge at Stenscholl to within 70 yd of the junction with Lon a'Mhuilinn

Ostracod Limestones	ft	in
24. Thin, dark calcareous shales	3	0
23. Dark grey, calcareous shale	1	0
22. Grey cementstone with ostracods		10
21. Thin, black shale		3
20. Dark grey, argillaceous limestone	1	2
19. Hard mudstone with shaly and sandy balls	1	10
18. Black, calcareous shale	1	3
17. Hard, grey limestone	1	0
16. Calcareous shales with bands of impure limestone	4	0
15. Indurated, black shale	3	0
Dolerite sill	approx 10	0
14. Indurated mudstone		11
13. Indurated shale	5	6
12. Very sandy limestone	1	0
11. Indurated, dark calcareous shales	6	0
Dolerite sill	approx 2	0
10. Black shale	4	0
9. Flaggy, white, calcareous sandstone	3	0
8. Argillaceous mudstone	1	6
7. Flaggy sandstone	2	0
6. Flaggy, argillaceous sandstone		6
5. Dark shale	1	0
Dolerite sill	approx 10	0
4. Indurated mudstone		6
3. Black shale	2	6
2. Flaggy, argillaceous sandstone	1	6
1. Indurated, black shale	2	6

The beds apparently dip downstream at a low angle. Immediately downstream from the entrance of the tributary Lon a'Mhuilinn an exposure in the west bank of the river shows a mass of breccia composed of fragments of dark shale, limestone and cementstone, marking the place where a fault crosses the stream. At a bend of the river about 200 yd further north and opposite a small island the following section is exposed in the west bank:

	ft	in
6. Shaly and pebbly limestone	2	6
5. Dark, argillaceous limestone	1	3
4. Pale brown, calcareous sandstone		10
3. Black, calcareous shale	2	8
2. Mudstone	3	0
1. Grey sandy and calcareous shales	2	0

The beds apparently dip downstream at about 5°. Opposite the middle of the island the sediments stop abruptly at a deep cleft which marks the position of a fault, on the north side of which is a rubbly mass of dolerite cut by a dyke. For the next 300 yd the river apparently runs in sill but near the mouth, low down in the western bank opposite Staffin Lodge is a small exposure of thin limestones, dark shales and a cementstone with ostracods resting on sill.

It is difficult to estimate the total thickness of the Ostracod Limestones exposed in this stream but there cannot be less than 70 ft of strata.

Lower beds than these exposed in Kilmartin River overlie the Lower '*Ostrea*' Beds in the cliff section south-east of Rubha Garbhaig (Beds 43-46, of the Rubha Garbhaig section p. 32). They consist of sandy marls and sandstone with *Viviparus* and a very dark brown, waxy clay with ostracods. Southwards these beds are cut out from the cliff section by a downward transgression of the upper leaf of sill, but northwards the dark brown clay is exposed low down on the western side of the cart-road 100 yd south of An Corran. Sediments caught up in the sill at An Corran belong to the Ostracod Limestones. They consist of calcareous shales, shaly limestones and mudstones, disturbed by small faults and a dyke.

A further small exposure of these beds lies 250 yd S.W. of An Corran and about 70 yd south-east of the road. It shows grey shale with loose blocks of ripple-marked sandstone. Though somewhat disturbed these beds are probably not far out of place.

The Ostracod Limestones must pass below sea-level some little distance west of Kilmartin River and are not seen again until the axis of the Jurassic syncline is crossed when they reappear on the coast north of Kildorais, in a small cliff just above high water mark 550 yd N.E. of Flodigarry Hotel as indurated white marl. On the north side of Eilean Altavaig (Flodigarry Island) about 6 ft of badly baked sediments are exposed, comprising calcareous shales with abundant *Euestheria* and a 1-ft bed of white limestone. A small quarry on the east side of the Flodigarry-Kilmaluag road and slightly north of west from Druim na Slochd exposed baked marls and cementstones with ostracods resting on sill and northwards another small quarry 300 yd W. N. W. of Tom na h-Uraich shows a few feet of indurated dark calcareous shale resting on sill. Baked shales and marls are again seen 350 yd further to the north-west in a small quarry above the sill.

In the small bay between Sgeir nan Eathar Bana and Stac Buidhe, Ostracod Limestones are exposed in the cliff. There are sediments below the sub-soil resting on a 15-ft leaf of sill and again between this and the lower leaf which forms the base of the cliff. Between Sgeir nan Eathar Bana and Balmacquien are several small patches of baked sandy shale and on the foreshore east of Bogha Ruadh is a small lenticle of black shale, calcareous shale and sandy beds enclosed in sill.

Ostracod Limestones are exposed in the bed of Kilmaluag River near its mouth and immediately north of the ford. They are indurated calcareous shales and mudstones resting on sill and dipping W.S.W. at about 15°. From these beds Malcolm MacGregor (1934, p. 395) has recorded *Viviparus sp.*, '*Unio*' *staffinensis* (Forbes), ostracods and *Euestheria murchisoni* (Jones). The low ground between this point and Kilmaluag is occupied by the Ostracod Limestones in the form of a shallow syncline the axis of which runs approximately east and west. The centre of the syncline must however be occupied by the overlying Mottled Clays which account for the marshy nature of the ground.

On the shore of Port Gobhaig, Kilmaluag Bay, the Ostracod Limestones are seen overlying the Lower '*Ostrea*' Beds (see Section, beds 12-19, p. 39). They represent about 23 ft of sandy and shaly beds with cementstones and marls and contain ostracods, *Euestheria murchisoniae*, *Viviparus sp.* and *Hydrobia praecursor* Sandberger. The general dip is southerly at about 20° but the lower beds rest on sill and are much disturbed and injected by it. Small exposures of indurated black shale between Shulista and the main road probably belong to the same series.

At the base of the cliff by the small promontory of Bun-idein in the middle of Lub a'Sgiathain a lenticle of baked shales and limestones may belong to the Ostracod Limestones but the beds have yielded no fossils. At the western extremity of this bay in Port Lag a'Bhleodhainn on the east side of Meall Tuath is a small cliff immediately above high water mark in the Concretionary Sandstones. A N.W. fault in the beach below the cliff throwing down to the north-east brings the Ostracod Limestones, here represented by a hard cementstone with ostracods, *Euestheria* and *Viviparus*, against the lower beds.

In Port Duntulm east of the castle three small lenticles of the Ostracod Limestones are exposed on the foreshore in sill. The most westerly of these lies under the castle and shows calcareous dark shales, a sandy bed and ?mottled clay all highly indurated and altered. The central lenticle is bisected by a north-south fault, to the west of which sandstones and shales are exposed and to the east, black shales and marls all badly baked by the sill. The eastern lenticle consists of altered cementstone.

Indurated and shattered calcareous shales are seen in the gravel pit on the north side of the main road south-east of Duntulm Castle, and again 150 yd to the south-east, west of Cnoc Roll. A small roadside cutting and quarry north-east of the cart-road at the south-western side of Cnoc Roll, shows at the eastern end sandy shales, in the middle part pale marls, and at the western end a small quarry in indurated calcareous shale.

The uppermost beds exposed in the Lon Onstatoin section belong to the Ostracod Limestones (see Section, beds 13-17, p. 41). Here shales, sandstones with *Viviparus*, and a cream-coloured mudstone lie immediately below the sill. At Peingown along the north-east side of the road leading from Flora Macdonald's Monument to Heribusta is a steep bank in which strata belonging to the Ostracod Limestones are exposed at the western end opposite a ruined chapel. They are indurated white and grey marls and fragmental shale dipping eastwards at about 10° and are brought against Lower '*Ostrea*' Beds sandstones to the east by an east-west fault (see p. 42). On the west the marls are dropped down to the west by several small step faults.

At the mouth of Lon Sgapail and extending eastwards along the foreshore to the second dyke (a multiple dyke) are about 25 ft of shales, limestones and sandstones resting on sill and dipping E.N.E. at 15-20° except between the two dykes where the beds are disturbed and dip south-east and south-west. The sequence in these beds is as follows:

Section at the mouth of Lon Sgapail

Ostracod Limestones	ft	in
16. Calcareous sandstone	1	6
15. Hard, black calcareous shale	2	9
14. Sandstone		11
13, Hard, grey calcareous shale	1	3
12. Soft sandstone		3
11. Hard, grey calcareous shale	1	0
10. Hard, grey marly shale	7	0
9. Soft, shaly sandstone	1	0
8. Hard, grey calcareous shale	2	3
7. Hard, grey, sandy limestone	1	5
6. Soft, greenish sandstone		4
5. Hard, grey, sandy limestone		2
4. Hard, black shale	1	4
3. Dark green, sandy shale	1	0
2. Dark grey, shaly limestone		9
1. Grey shale with hard sandy bands	2	6
Dolerite sill		

These beds probably represent the lower sandy portion of the Ostracod Limestones exposed in Kilmartin River (see Section p. 44).

Along the beach 20 yd N.W. of Lon Sgapail a lenticle in the sill is composed of indurated sandstone, sandy shale, sandy limestone and shales. Other small lenticles of baked shale are exposed on the north side of Gairbh-sgeir, and at the southern side of Camas Mor.

Beds probably belonging to the Ostracod Limestones are to be seen in a small quarry 500 yd N. of the Highland Home Industries Factory north of Kilvaxter, and in a stream bed 100 yd further to the north-east. The sediments are indurated sandy shales and limestone dipping W.S.W. at about 5°. The horizon of other small exposures of indurated shales in Kilvaxter Burn 300 yd west of the road and in the burn half a mile south of Balgown, also west of the road, cannot be determined with any certainty; it is even doubtful that these beds are *in situ.*

South of Prince Charles's Point the Ostracod Limestones are again exposed on the beach. They consist of a hard, grey, sandy limestone 3 in, resting on an irregular carbonaceous, sandy limestone 5 in, on dark, carbonaceous shale with ostracods 2 ft. The beds are high up in the series and to the south pass below the Mottled Clays.

In the east of North Trotternish, south of Staffin there are a few isolated exposures of the Ostracod Limestones. At Clachan, a short distance east of the Dun, is a small quarry in indurated shale and there are several fragmentary exposures nearby in the same material. North-east from here, across the main road a little way south-east of the Free Church, baked marls, shales and sandstones are exposed in a small pit to the south of a cart-road and in a gravel pit near by. The beds are much altered especially in the gravel pit which shows at its southern end a leaf of sill transgressing the sediments of which about 16 ft are here exposed. At Elishader two small quarries on the north-east side of the main road give sections in the Ostracod Limestones. The northerly one shows soft sandstones and marly, shaly and sandy beds in all about 5 ft thick as a lenticle in sill. The southerly exposures show sandy grey marl 4 ft, on soft yellow marl 10 in, on black shales with ostracods and *Euestheria murchisoniae* 3 ft, again enclosed between two leaves of sill. The relationship of these beds to the cliff section a short distance away is difficult to interpret. At the Loch Mealt fall the base of the sill rests on beds low down in the Concretionary Sandstones and in these road-side pits Ostracod Limestones are enclosed in the same sill, i.e. the sill has apparently displaced 120 ft of strata. It is clear, therefore, that between the pits and the cliff top the sill has transgressed downwards through the Lower '*Ostrea*' Beds and part of the Concretionary Sandstones on a line parallel to the coast. In the most southerly of these two quarries the upper leaf of sill rests on the shales below without disturbing them, but within the body of the shale are planes of crush and the surface of the lower sill is covered with brecciated material suggesting that the upper sill was already in place when the lower was intruded.

At Raisaburg there is a small exposure of baked marl with ostracods in the bank of Lon Buideil about 150 yd before the stream enters the south-west corner of Loch Mealt.

The Ostracod Limestones have not been seen *in situ* south of Tottrome but fragments of shale with ostracods and 'beef' and thin argillaceous limestones are abundant in the landslip north-west of Loch Leathan.

Near the source of the most northerly stream at Tottrome is a section showing about 5 ft of indurated sediments—limestone and '*Estheria*' shale dipping at 10° a few degrees south of west. A large slipped mass 50 yd south-west of the stream was composed of ostracod shales 3-4 ft, grey cementstones with *Euestheria* 2 ft, black shales 1ft. Below the sill and 100 yd downstream from the first exposure the following strata overlie the Lower '*Ostrea*' Beds:

	ft	in
6. Impure, shelly limestone with 'beef'	1	2
5. Calcareous grit	1	6
4. Sandy marl		2
3. White cementstone with *Viviparus*	1	8
2. Black shale		7
1. Massive sandstone with doggers	10	0

There appear to be about 15 ft of shale between the top of this section and the base of the overlying sill.

A few feet of dark indurated shale can be seen below a transgressing sill S.S.W. of Dun Connavern and west of Culnaknock; and there is a small patch of baked, spotted shale at Marishader.

In Vaternish, Ostracod Limestones are exposed at Port na Cagain. Lenticles of sediment enclosed and altered by the sill include a white and grey, marly limestone with tufaceous bands and abundant ostracods, dark ostracod shales and a white sandstone.

On the beach west of Stein sediments belonging to the Ostracod Limestones are exposed as follows: west of a 13-ft multiple dyke, black shales and a white sandstone; east of the dyke and north of the piers, black shale in very thin beds 2 ft 6 in, above grey shale with marly bands and thin algal limestones 3 ft, above 10 ft of soft greenish-white sandstone. East of this are thin black shales with 'beef' and ostracods followed by the greenish-white sandstone.

At this locality the author found a fossil coniferous tree trunk 8 inches in diameter and over 5 ft long lying prostrate on top of the sandstone, covered and surrounded by grey shale. This appears to have been the remains of a large tree as the beach in the vicinity was strewn with fragments of fossil wood. The dip of the strata here is about 2° to the north-east.

The algal band in this section is an earthy limestone 1½ in thick, with dark purplish, spheroidal nodules of about ¼ inch diameter in the upper half. In thin section the rock is seen to consist of a dense mass of broken ostracod carapaces set in a dark, granular calcite. The nodules are composed of a dense, very finely granular calcite with traces of algal filaments. These algal remains are very fragmentary but appear to consist of fairly straight tubules of about 0·01 mm diameter. Though not specifically identifiable it is clear that these are not the species of algae found in the Lower '*Ostrea*' Beds but are much more like those described from the '*Estheria*' shales in the Lealt River (Anderson 1948, p. 126).

At the southern end of Loch Bay an outcrop of the Ostracod Limestones is hidden beneath the landslip at Slochd Mor. Angular fragments of cementstone, grey marl and ostracod shales are common. The marls contain *Viviparus*, *Neomiodon*, fish scales, plant fragments, ostracods and *Euestheria*.

MOTTLED CLAYS

Immediately succeeding the Ostracod Limestones are about 40 ft of marly clays with beds of calcareous sandstone. The clay is grey, red, green and blue mottled, and black, and contains sporadic algal (?) nodules from ½ in to 2 inches in diameter and small septaria. The sandstones are hard, fine-grained calcareous beds with a slightly greenish tinge. Though this group has not hitherto been recognized in North Skye, it has been recorded in Straithaird as 'Blue shaly marl with blue or white calcareous nodules up to 30 or 40 feet' (Wedd *in* Peach and others 1910, p. 121). The calcareous grits, which in Raasay yielded fossils of Cornbrash age, are most likely part of the Mottled Clays (Lee, 1920, p. 58). The Mottled Clays are as a rule unfossiliferous, but a black clay near the top of these beds in Staffin Bay is full of obscure plant remains and the majority of the concretionary nodules are probably of algal origin. A fish tooth was found by Malcolm MacGregor (1934, p. 401) in a Mottled Clay sandstone at Poll an Staimh, north of Uig.

The characteristic red and green mottling of the clays and the presence of fresh feldspars in the sandstones probably indicate that these beds represent a period of arid climate between the deposition of the Ostracod Limestones and the gradual establishment of marine conditions in the succeeding strata.

The most complete section of the Mottled Clays is that exposed on the beach at the south-western corner of Staffin Bay, between Point 1 (Fig. 8) and the River Brogaig. Reference points in Staffin Bay are illustrated in Figs. 9-12.

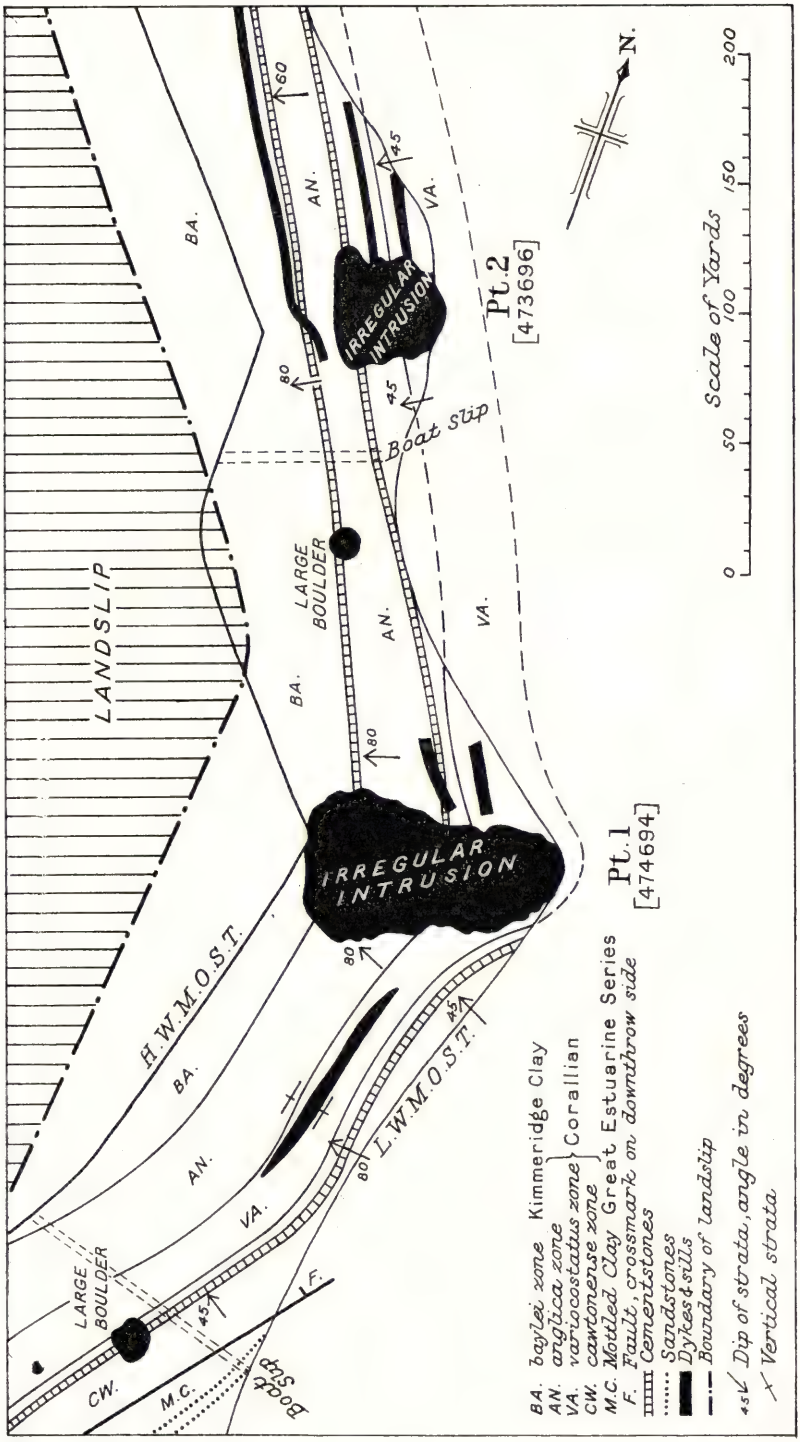


FIG. 8. *Map of Jurassic strata in Staffin Bay, coast east of Digg. Grid references in square brackets*

Section 400 *yd south of Point* 1 [474694], *Staffin Bay*

	ft	in
Upper 'Ostrea' Beds		
21. Black, calcareous shale	1	0
20. Thin, sandy *Ostrea* limestone with a layer of cone-in-cone near the middle	1	0
19. Black shale with well-preserved *Neomiodon*		6
18. Rusty, black shales with *Liostrea hebridica*	8	0
17. Black, calcareous shale	4	0
16. Indurated shale with *Liostrea hebridica*	2	6
15. Indurated shale	2 in to 3	
Dolerite sill, thickness variable but up to	15	0
14. Black shale	1	6
13. Dark limestone with *Liostrea hebridica*		6
12. Dark shales with *Liostrea hebridica*	3	0
11. Black shale	1	9
10. Dark limestone with *Liostrea hebridica*		4
9. Grey shales with abundant *Neomiodon*	?6	0
Mottled Clays		
8. Red and green, mottled clay with an irregular bed of black clay full of plant fragments near the top; irregular calcareous concretions, septaria and algal nodules scattered throughout	20	0
7. Current-bedded, greenish-white, calcareous sandstone	1	0
6. Green, sandy clay	1	4
5. Current-bedded, greenish-white calcareous sandstone	1	7
4. Red and green, mottled clay	8	0
3. Current-bedded, greenish-white, calcareous sandstone	1	0
2. Red and green mottled clay	?6	0
Strike fault		
Upper 'Ostrea' Beds		
1. Grey shale with *Neomiodon*	2	0

This section is in a wedge of sediments let down by faults to the north and south. The Mottled Clays must underlie the greater part of the beach at the southern end of Staffin Bay and the presence of this soft, easily eroded material probably accounts for the smooth contour of this part of the bay.

Northwards at the seaward extremity of the boat-slip a N.E. fault throwing down the beds to the north brings Lower Corallian shales (*Cardioceras cawtonense* Zone) against the Mottled Clay.

At the northern end of the Point 5 [472708] (Fig. 10) section the base of the Upper '*Ostrea*' Beds is again seen resting on a black clay with plant fragments, below which is typical red and green mottled clay. The full thickness of this group is not here exposed as a strike fault on the seaward side cuts across the beds just below the uppermost calcareous sandstone and repeats the Belemnite Sands and Upper '*Ostrea*' Beds (see Section of beach at Point 5, p. 52).

From here northwards to within a short distance of Point 6 [470712] the Mottled Clays are well seen in the beach near low-water mark underlying Upper '*Ostrea*' Beds.

The Mottled Clays probably occupy the centre of a shallow syncline north of Kilmaluag but are not exposed.

Half-way between Prince Charles's Point and Kilbride Point the Mottled Clays crop out on the beach, evidently overlying the Ostracod Limestones a short distance to the north, and here contain thin sandstones as in Staffin Bay. At Port Kilbride the clays are baked by the intrusive dolerite which forms Kilbride Point and Geodha

Dubh. On the south side of Geodha Dubh mottled clay is exposed below the sill but is very much altered, the clay being converted into a hard, dark, shaly material whereas the concretionary nodules have been changed into a white chalky substance, and stand out very conspicuously. The section here shows: Indurated, black shales with white nodules (mottled clay) 12 ft, on Sandstone 1 to 2 ft; on Indurated, marly shale 4 ft. The lower beds, being less affected by the intrusion, approach more closely to the normal lithology of this series.

In Poll an Staimh, a small bay on the north side of the Stack of Skudibrugh, is a section of the Mottled Clays showing an unusual development of one of the sandstones. The section shows 5-6 ft of calcareous sandstones and " pebble " beds resting on grey shale 1 ft, on grey, green, red and blue mottled clays. The " pebble " beds are actually calcareous sandstones with numerous algal(?) nodules and septaria, and an occasional pebble of quartz. The matrix has a dark green colour and the nodules weather out white, though they have the characteristic bluish-purple colour of algal concretions when freshly broken. In thin section the algal nodules occasionally show tubules but they are never sufficiently well-preserved to be identified even generically.

Malcolm MacGregor (1934, p. 401) referred these beds tentatively to the Cretaceous but their characteristic lithology and the presence of the underlying typical mottled clays, which are well exposed at low tide, indicate clearly that these " pebble " beds are simply a sandy portion of the Mottled Clays of Staffin Bay which have been slightly baked by the overlying sill.

The Mottled Clays are not exposed south of Uig but E.N.E. of the Old Man of Storr the landslip contains a mass of grey and red mottled clay resting on a large fragment of dolerite sill. Thus it is certain that these clays crop out below the lava scarp at least as far south as this.

UPPER 'OSTREA' BEDS

The Upper '*Ostrea*' Beds are only to be seen in North Trotternish where the Mottled Clays are overlain by 35 ft of rusty black shales and grey calcareous shales with two thin limestones, which represent the re-establishment of marine-estuarine conditions similar to those which obtained during the deposition of the Lower '*Ostrea*' Beds. The subdivision is extremely fossiliferous, some strata being chiefly composed of shells, but relatively few species are represented and the great majority belong to the genera *Liostrea* and *Neomiodon.*

During the survey of this area the following species were collected at Point 5 in Staffin Bay: *Neomiodon brycei* (Tate), *N. cunninghami* (Forbes), *N. staffinensis?* Anderson and Cox, *Staffinella* cf. *macullochi* (Forbes), *Anisocardia* (*Antiquicyprina*) *cucullata* (Tate), *Liostrea hebridica*(Forbes), *Isognomon murchisoni* (Forbes), *Neridomus* (*Staffinia*) *staffinensis* (Forbes), *Quenstedtia? forbesi* Anderson and Cox and *Zebina caledonica* (Tate).

Forbes and Tate recorded several other species but as these authors did not distinguish any of the subdivisions of the Great Estuarine Series the exact horizon of these forms can only be determined by future collecting.

The most southerly exposure of the Upper '*Ostrea*' Beds is in the south-west corner of Staffin Bay south of Point 1 [474694] (see p. 50). Here exposed in a low cliff are contorted, rusty, black shales passing upwards at the northern end of the section into shales with *Liostrea hebridica.* The sediments are intruded by an irregular mass of dolerite. This locality is undoubtedly that visited by Murchison—' in the low and ruinous cliffs of blue shale associated with zeolitic and amygdaloidal trap on the north-eastern (= south-western) shores of Loch Staffin, were found during my late excursion with Professor Sedgwick flattened masses of shelly limestone containing five species of cyclas, one paludina, one neritina? one ostrea, one mytilus, and some undescribed bivalves ' (Murchison, 1829, p. 358). 'North-eastern' is clearly a misprint for 'south-western' as Staffin Bay has no northern or eastern shore. Murchison's list is almost identical with that given above, his *Cyclas* is '*Cyrena*' (*Neomiodon*), the *Paludina* was probably *Viviparus scoticus*, the *Neritina?* is *Neridomus staffinensis*, the *Ostrea* is *Liostrea hebridica*, the *Mytilus* is *Isognomon murchisoni*. The undescribed bivalves were apparently collected from loose blocks of the Belemnite Sands (see Tate *in* Bryce 1873, p. 346 and Forbes 1851, p. 110).

In the beach below this section, about 20 ft of black shales with abundant *Liostrea hebridica* are exposed dipping westwards at angles varying from 30-90° into which an irregular tongue of sill is intruded. The lowest beds of the Upper '*Ostrea*' Beds, i.e. shales with *Neomiodon* are here seen resting on the Mottled Clays. A north-south strike fault near low water mark repeats the Upper '*Ostrea*' Beds on the seaward side and at very low tide *Neomiodon* shales can be seen brought against the Mottled Clays by this fault.

The Upper '*Ostrea*' Beds and the Mottled Clays here comprise a wedge-shaped mass thrown down by faults to the north and south. The southern fault is small and displaces the Upper '*Ostrea*' Beds only a few feet, but the northern fault with a bigger throw brings Upper '*Ostrea*' Beds against Mottled Clays. Within a very few yards however a second, almost parallel fault throws down the beds to the north and brings Mottled Clays against Lower Corallian shales. At Point 3 [473698] the Upper '*Ostrea*' Beds are cut out by a strike fault but to the north at Point 4 [473701] there appear to be a few feet of shales belonging to this group below the Belemnite Sands but the beds are covered even at low tide.

At Point 5 [473708], Staffin Bay there is a complete section of the Upper '*Ostrea*' Beds repeated to seaward by a strike fault. They here consist of 30 ft of dark shales with *Neomiodon* and *Liostrea*, in places in the form of shell beds, and with two thin limestones near the middle (see p. 51).

Section in the beach at Point 5 [473078], *Staffin Bay*

Oxford Clay	ft	in
26. Grey shale with *Cardioceras spp.*, *Parallelodon semulus* (Phillips) and *Pinna sp.;* and thin calcareous ribs	60	0
25. Dark grey cementstone weathering red	4 in to	5
24. Grey shale with *Cardioceras spp.* and thin calcareous ribs	14	0
23. Dark grey cementstone weathering red	4 in to	5
22. Dark grey shale with *Quenstedtoceras spp.*	15	0
21. Dark grey cementstone weathering yellow	1	0
20. Dark grey shale	1	9
19. Dark grey cementstone weathering yellow	6 in to 1	0
18. Dark grey shale with *Kosmoceras spp.* and belemnites, concretionary at the base	30	0
Belemnite Sands		
17. Hard calcareous concretionary bed with belemnites, weathering red		9
16. Dark green shale with belemnites	1 ft 6 in to 2	0
15. Hard, calcareous, concretionary and pebbly bed with belemnites		6
14. Hard calcareous concretionary bed weathering yellow	4 in to	6
13. Grey-green, streaky, shaly sands with *Pleuromya spp.* etc.	8	6
12. Hard, calcareous sandstone with *Modiola*, *Pleuromya* and *Trigonia*	2	0
11. Grey-green, streaky, shaly with *Liostrea* and *Pleuromya*	10	0
Upper 'Ostrea' Beds		
10. Shell bed composed of *Neomiodon spp.*	4 in to	6
9. Dark grey shale with abundant *Neomiodon*	1 ft to 2	6
8. Grey-green shale with a band rich in *Liostrea* at the base	10	0
7. Dark grey shale	3	6

	ft	in
6. Hard, grey limestone with *L. hebridica*	2	0
5. Dark grey shale with *L. hebridica*	1	11
4. Grey shale	2	6
3. Hard, grey, shelly limestone with ½ in of cone-in-cone at the top	1	0
2. Grey shale	10	0
Mottled Clays		
1. Red and green, mottled clay	20	0
Dolerite sill and strike fault		

To the seaward of the sill beds 2-17 are repeated by the strike fault.

At the northern end of the Point 5 section a strike fault cuts out the Upper '*Ostrea*' Beds and Belemnite Sands and throws Mottled Clays against Lower Oxford Clay.

A few yards south of Point 6 (Fig. 10) the whole of the Upper '*Ostrea*' Beds is exposed resting on Mottled Clays and thrown against Upper Corallian on the landward side by a strike fault. The dip is westwards at 45°. An east-west fault separates these beds from a small wedge of sediments to the north in which fragmentary exposures indicate that the succession is complete from the Mottled Clays to the Lower Oxford Clay without the intervention of strike faults.

In the west, Upper '*Ostrea*' Beds with the overlying Belemnite Sands and Oxford Clay must floor the valley once occupied by Loch Chaluim Chille. Murchison (1829, p. 311) examined beds in the canal cut to drain the loch and recorded blue shales with 'Ammonites Königi, ostreae in masses, many belemnites, flattened tellinae, etc.' Clearly the canal must have cut through Ostracod Limestones ('flattened tellinae?' = *Euestheria murchisonae* (Jones)), Mottled Clays, Upper '*Ostrea*' Beds (' Ostreae in masses'), and Belemnite Sands ('many belemnites' and 'Ammonites Königi') to the Oxford Clay.

BELEMNITE SANDS

Overlying the Upper '*Ostrea*' Beds are about 20 ft of grey-green, argillaceous sands with a 2-ft hard, calcareous sandstone near the middle and thin, concretionary and pebbly beds at the top. The sands are soft and fine grained with much carbonaceous material and a characteristic streaky appearance. The constituent quartz grains are angular and there is a little feldspar. The middle sandstone is simply a portion of the sands cemented with calcium carbonate, resulting in a grey-green, hard, muddy, calcareous sandstone. The pebbly and concretionary beds represent a somewhat coarser phase of the sands irregularly cemented by calcium carbonate. They contain small quartz pebbles and, especially the upper band, numerous belemnite guards (see Section, Beds, 11-17, pp. 52, 53).

The lower sands (below the middle sandstone) contain *Liostrea hebridica* Forbes, *Oxytoma inequivalve* (J. Sowerby) and *Pleuromya* cf. *alduini* (Brongniart.)

The central sandstone is very fossiliferous, most likely because the calcareous cement has preserved the fossils which in the softer beds have probably been leached out by percolating water. This bed contains: *Astarte staffinensis* Anderson and Cox, *A. extensa* Phillips, *Camptonectes lens* (J. Sowerby), *Neomiodon brycei* (Tate), *Liostrea hebridica* (Forbes), *Pleuromya alduini* (Brongniart), *P. securiformis* (Phillips), *P. uniformis* (J. Sowerby).

The upper sands contain: *Isognomon promytiloides* Arkell [= cf. *isognomoides* (Stahl)], *Modiola bipartita* J. Sowerby, *Pleuromya alduini* (Brongniart), *P. securiformis* (Phillips), *Trigonia* (*Vaugonia*) *tripartita* Forbes, *Hydrobia praecursor* Sandberger, *Littorina* cf. *muricata* J. Sowerby, *Belemnites sp.* (*oweni* type).

This fauna clearly indicates that truly marine conditions followed the marine-estuarine episode of the Upper '*Ostrea*' Beds. The lithology, however, shows that these beds were laid down in shallow water, indeed, as will be shown later, even the succeeding Oxford Clay shales cannot have been laid down far from land.

The presence of such forms as *Pleuromya alduini*, *P. securiformis*, *P. uniformis*, *Isognomon* cf. *isognomoides* (Stahl) suggests that these beds are the equivalents of the Kellaways Beds of England. A single ammonite fragment was found in the middle sandstone by the author which Dr. J. H. Callomon has identified as a *Kepplerites*, which again suggests a Kellaways age. No exact zonal correlation can therefore be made but in general terms there can be little doubt that the Belemnite Sands are to be regarded as approximately contemporaneous with the Brora Roof Bed, as was suggested by Malcolm MacGregor (1934, p. 400). In Strathaird a black sandstone at the foot of the sea-cliff near Carn More has yielded a Kellaways fauna including *Ornithella kellowaysensis* (Davidson), and *Kepplerites gowerianus* J. de C. Sowerby sp. (Wedd *in* Peach and others 1910, p. 128).

Thus the Great Estuarine Series can be said with reasonable certainty to extend from the *Parkinsonia parkinsoni* Zone of the Bajocian to and including the *Proplanulites koenigi* of the Lower Callovian and Murchison's record of this zone fossil from Loch Chaluim Chille is probably correct.

REFERENCES

ANDERSON, F. W. 1948. Algal beds in the Great Estuarine Series of Skye. *Proc. Roy. Phys. Soc. Edin.*, **23**, 123-42.

—— and COX, L. R. 1948. The 'Loch Staffin Beds' of Skye, with notes on the Molluscan fauna of the Great Estuarine Series. *Proc. Roy. Phys. Soc. Edin.*, **23**, 103-22.

BRYCE, J. 1873. On the Jurassic rocks of Skye and Raasay. *Quart. J. Geol. Soc.*, **29**, 317-51.

CASEY, R. 1952. Some Genera and Subgenera, mainly new, of Mesozoic Heterodont Lamellibranchs. *Proc. Malac. Soc.*, **29**, 121-76.

—— 1956. The Neomiodontidae, a new family of the Arcticacea (Pelecypoda). *Proc. Malac. Soc.*, **31**, 208-22.

COX, L. R. 1950. Bathonian *Viviparus*-like gastropods. *Geol. Mag.*, **87**, 228-10

FORBES, E. 1851. On the Estuary Beds and the Oxford Clay at Loch Staffin in Skye. *Quart. J. Geol. Soc.*, **7**, 104-13.

FORSYTH, I. H. 1959. A marine shell-bed near the base of the Estuarine Series in Raasay. *Trans. Edin. Geol. Soc.*, **17**, 273-5.

HUDSON, J. D. 1962. The Stratigraphy of the Great Estuarine Series (Middle Jurassic) of the Inner Hebrides. *Trans Edin. Geol. Soc.*, **19**, 139-65.

—— 1963. The recognition of salinity-controlled mollusc assemblages in the Great Estuarine Series (Middle Jurassic) of the Inner Hebrides. *Palaeontology*, **6**, 318-26.

—— 1963a. The ecology and stratigraphical distribution of the invertebrate fauna of the Great Estuarine Series. *Palaeontology*, **6**, 327-48.

JUDD, J. W. 1878. The secondary rocks of Scotland. Third Paper. The strata of the Western Coast and Islands. *Quart. J. Geol. Soc.*, **34**, 660-743.

LEE, G. W. 1920. The Mesozoic Rocks of Applecross, Raasay and North-East Skye. *Mem. Geol. Surv.*

MACGREGOR, MALCOLM. 1934. The sedimentary rocks of North Trotternish, Isle of Skye. *Proc. Geol. Assoc.*, **45**, 389-406.

MILLER, H. 1858. *The Cruise of the Betsey*. 1st Edit. Edinburgh.

MURCHISON, R. I. 1829. Supplementary Remarks on the Strata of the Oolite Series, and the Rocks associated with them, in the Counties of Sutherland and Ross, and in the Hebrides. *Trans. Geol. Soc.*, **2**, 353-68.

Peach, B. N., Horne, John, Woodward, H. B., Clough, C. T., Harker, A. and Wedd, C. B. 1910. The Geology of Glenelg, Lochalsh and the south-east Part of Skye. *Mem. Geol. Surv.*

Richey, J. E., MacGregor, A. G. and Anderson, F. W. 1961. Scotland: The Tertiary Volcanic Districts. 3rd Edit. *British Regional Geology, Geol. Surv.*

Chapter IV

JURASSIC: OXFORD CLAY
TO KIMMERIDGE CLAY

THE BELEMNITE Sands in North Skye are succeeded by a series of dark blue-grey shales with thin grey cementstones and lines of calcareous nodules. At the base the shales become bituminous but they are never sufficiently rich to be classed as oil-shales. The fauna consists predominantly of ammonites and belemnites, but at certain horizons are bands locally rich in lamellibranchs. Plant fragments, foraminifera and ostracoda are found throughout and occasionally a brachiopod.

A large collection of ammonites was made during the survey of the area and submitted for identification to the late L. F. Spath who gave valuable assistance in the delimitation of the zones into which the shales have been divided. Except for occasional specimens extracted from a cementstone the material is very badly preserved; nevertheless it has been found possible to apply with certain modifications demanded by the field evidence the zonal scheme which is in use in England. There can be no doubt that the blue shales above the Great Estuarine Series of North Trotternish are equivalent to the Oxford Clay, Corallian and the lower part of the Kimmeridge Clay of England, but they are unique in that the lithology of these beds in Skye is the same throughout, in marked contrast to the varied lithology which is the rule in England.

In the field these shales fall naturally into five divisions according to the ammonite faunas they contain. The zonal scheme is a subdivision of these major groups. With the possible exception of the *Cardioceras cordatum* Zone it is not easy to distinguish the individual zones except by detailed collecting, whereas the major divisions are recognizable without difficulty.

The following are the major divisions based on the ammonite succession:

e. *Pictonia* Beds
d. *Amoeboceras* Beds
c. *Cardioceras* Beds
b. *Quenstedtoceras* Beds
a. *Kosmoceras* Beds.

The zonal scheme adopted in this memoir is:

Kimmeridge Clay		*Pictonia baylei* Zone
Corallian	*Amoeboceras* Beds	*Ringsteadia anglica* Zone *Perisphinctes variocostatus* Zone *Cardioceras cawtonense* Zone
Upper Oxford Clay	*Cardioceras* Beds	*Cardioceras cordatum* Zone
	Quensdtedtoceras Beds	*Quenstedtoceras mariae* Zone
Middle Oxford Clay		*Quenstedtoceras lamberti* Zone
	Kosmoceras Beds	*Peltoceras athleta* Zone
Lower Oxford Clay		*Kosmoceras castor* & *K. pollux* Zone
		Kosmoceras jason Zone

OXFORD CLAY

The Oxford Clay in North Skye is very like its equivalent in Dorset, a dark blue-grey clay with grey cementstones and lines of concretionary nodules. Its presence in Skye was first recognized by Forbes (1851, p. 106) who described a section in Staffin Bay obviously not far from the locality here referred to as Point 3 [473698], (Fig. 9). He stated that overlying the Loch Staffin Beds he found 'numerous specimens of *Ammonites cordatus* and *Belemnites Owenii* and *Beaumontianus* indicating the age of these shales beyond a question to be that of the Oxford clay'.

These beds contain ammonites and belemnites in great abundance and in addition: *Astarte* cf. *cordata* Trautschold, *Nuculana sp. nov.*, *Terebratula* cf. *subsella* Leymerie and *Pholadomya sp.* Arkell (1945) recorded *Cardioceras ashtonese* Arkell, *C. costicardia* S. S. Buckman, *C.* (*Scarburgiceras*) *excavatoides* Maire and *Peltoceras gerberi* (Prieser) from the Oxford Clay of Staffin Bay but only the second species in this list was found in recent collecting.

On the basis of the ammonite fauna the Oxford Clay has been divided into the following zones:

	Zone	*Subzone*
Upper Oxford Clay	*Cardioceras cordatum*	C. *excavatum* C. *cardia*
	Quenstedtoceras mariae	C. *praecordatum* *Q. vertumnus*
Middle Oxford Clay	*Q. lamberti* *Peltoceras athleta*	
Lower Oxford Clay	*Kosmoceras castor* and *K. pollux* *Kosmoceras jason*	

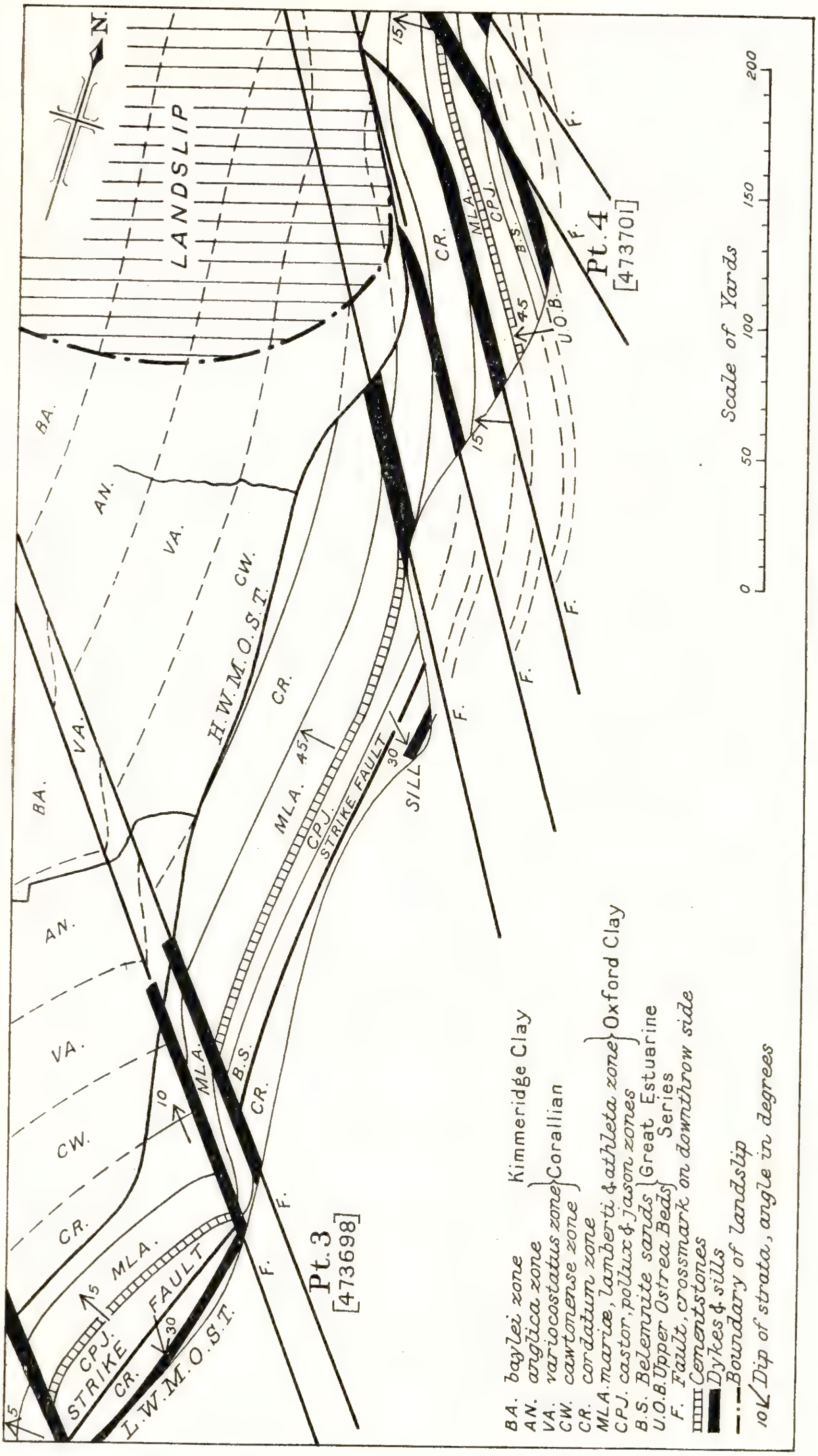


FIG. 9. *Map of Jurassic strata in Staffin Bay, coast east of Loch Leum nam Bradh. Grid references in square brackets*

i. Zone of *Kosmoceras jason*. The *K. jason* Zone has been recognized at Points 3 (473698), 4 (473701) and 5 (472708) in Staffin Bay[1]. It is represented by about 20 ft of shale with ammonites determined as *Kosmoceras* (*Gulielmites*) *spp*. some of which are allied to *K. conlaxatum* S. S. Buckman (*K. conlaxatum* S. S. Buckman = *K. jason* Reinecke sp.).

ii. Zone of *Kosmoceras castor* and *K. pollux*. The 6-7 ft of shale succeeding the *K. jason* Zone at Point 5 contain *Kosmoceras* (*Gulielmites*) *sp*. with *Kosmoceras* (*Spinikosmoceras?*) *sp*. and according to Spath represents the Zone of *K. castor* and *K. pollux* = the *reginaldi* Zone of A. Morley Davies (1916) = the *coronatum* Zone of Buckman = the *elizabethae* Zone of Neaverson (1925). (The name *coronatum* Zone proposed by d'Orbigny in 1825 has priority.)

iii. Zone of *Peltoceras athleta*. The succeeding 3 ft of shale at Point 5 contains Kosmocerates of the *proniae* type and may therefore be tentatively correlated with the *P. athleta* Zone which is here taken to be the equivalent of the *duncani* and *athleta* zones of Morley Davies and Neaverson, the *duncani* Zone of Spath 1926, the *spinosum* = *ornatum* Zone of Buckman (1913), the *proniae–athleta* zone of Pringle (1930), and the *athleta–duncani* zone of Arkell (1933).

iv. Zone of *Quenstedtoceras lamberti*. At Points 3, 4 and 5 in Staffin Bay this zone is represented by 4 ft of shale with Kosmocerates of the '*Bikosmoceras*' *deficiens* group of S. S. Buckman, Quenstedtocerates like *Q. gregarium* S. S. Buckman, Eboracicerates like *E. cadiforme* S. S. Buckman, and at the base forms resembling *Kosmoceras spinosum* (J. de C. Sowerby) (= *ornatum* Douvillé). The fauna is suggestive of the *lamberti* Zone as developed in Dorset.

v. Zone of *Quenstedtoceras mariae*. The next 24 ft of shale at Points 3, 4 and 5 have been referred to the *Q. mariae* Zone. In the lowest 6 ft the fauna belongs to the *Quenstedtoceras* group (see p. 62) whereas the uppermost 18 ft contain a quite distinct *Cardioceras* fauna, so that the zone is readily divided into two subzones.

a. Subzone of *Quenstedtoceras vertumnus*.

Six feet of shale containing *Quenstedtoceras* (*Vertumniceras*) *vertumnum* (Leckenby), Quenstedtocerates allied to *Q. lamberti* (J. Sowerby) and *Poculisphinctes sp*.

b. Subzone of *Cardioceras praecordatum*.

Eighteen feet of shales containing *Cardioceras* (*Scarburgiceras*) *praecordatum* (R. Douvillé), *Cardioceras sp.* like a large *C. costellatum–anacanthum* and *Cylindroteuthis oweni* (Pratt). This fauna may be compared with that found at Warboy's Pit, Huntingdonshire.

vi. Zone of *Cardioceras cordatum*. The uppermost beds of the Oxford Clay in Staffin Bay consist of 60 ft of shale and as exposed at Points 3, 4 and 5 contain a rich fauna of Cardiocerates indicative of the *C. cordatum* Zone. It is here divisible into two subzones:

a. Subzone of *Cardioceras cardia* (= *lower cordatum*).

Thirty feet of shale with *Cardioceras* cf. *costicardia* S. S. Buckman, *C.* cf. *costellatum* S. S. Buckman, *C.* cf. *cardia* S. S. Buckman, *C.* cf. *cordatum* auctorum, *C.* cf. *rouilleri* (Nikitin) Lahusen, and *Peltoceratoides* aff. *williamsoni* (Phillips). This subzone probably represents the equivalent of the uppermost Oxford Clay at Studley Brickyard and of Dorset, and of the Lower Calcareous Grit of Yorkshire.

---

[1] Reference points in Staffin Bay are indicated in Figs. 8-12.

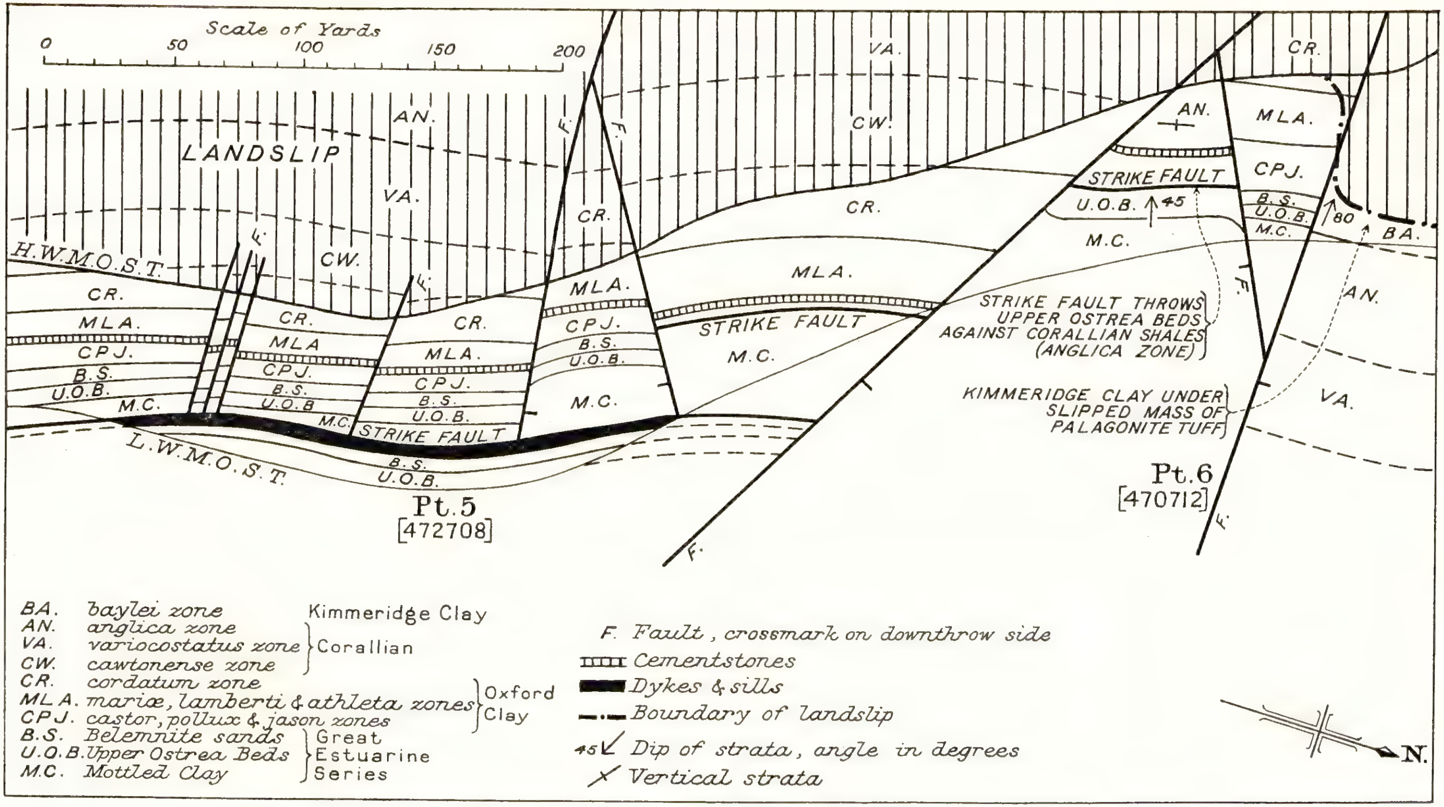


FIG. 10. *Map of Jurassic strata in Staffin Bay, coast east of Loch Langaig. Grid references in square brackets*

b. Subzone of *Cardioceras excavatum* (= upper *cordatum*).

Thirty feet of shales with *Cardioceras excavatum* (J. Sowerby), *C.* cf. *costellatum* S. S. Buckman, *C.* cf. *nikitianum* (Lahusen), *C.* cf. *papilioniense* Boden, *C.* cf. *tenuicostatum* (Nikitin) and *C.* cf. *coelatum* Pavlov. The fauna is very like that of the *C. excavatum* limestone of Ardassie Point. This subzone is probably the equivalent of the Lower Calcareous Grit of Wiltshire and approximates to the Zone of *Ammonites catena* Arkell 1936.

DETAILS

The most complete and least disturbed section of the Oxford Clay is that to be found at Point 5, Staffin Bay, for though several small faults cross the beach they are parallel to the dip of the beds and do not cause any great dislocation of the strata (see section p. 52). At Points 3 and 4 the Oxford Clay is disturbed by small faults and dykes, especially at Point 4 where the Kildorais Fault ends in numerous virgations which split up the strata into wedge-shaped fragments.

Section in the beach of Staffin Bay, midway between Points
3 [473698] *and* 4 [473701]

	ft	in
Oxford Clay		
13. Dark blue shale with *Cardioceras*, *Peltoceratoides*, *Pachyteuthis*, *Astarte* cf. *cordata*, Trautschold, *Nuculana sp. nov.* and *Parallelodon aemulum* (Phillips)	30	0
12. Dark grey cementstone weathering red	4 in to 5	
11. Dark blue shales with *Quenstedtoceras* and *Nuculana sp. nov.*	15	0
10. Hard grey cementstone weathering yellow	9 in to 12	
9. Dark blue shale	1	7
8. Hard grey cementstone weathering yellow	6 in to 12	
7. Dark shales with *Kosmoceras* and fragments of wood; a few feet of bituminous shale at the base with *Hibolites sp.*	24	0
Belemnite Sands		
6. Hard, calcareous, concretionary, sandy bed weathering red, with belemnites		9
5. Dark green shale with belemnites	1	6
4. Hard, calcareous, concretionary and pebbly bed with belemnites		6
3. Grey-green streaky shaly sands with *Pleuromya* etc.	4	0
2. Hard calcareous sandstone with *Pleuromya*, *Modiola*, *Trigonia* etc.	2	6
1. Grey-green, streaky, shale with *Ostrea* and *Pleuromya*	10	0
Strike fault repeating Oxford Clay.		
Oxford Clay		
d. Dark blue shales	6	0
c. Hard, calcareous shales with belemnites		3
b. Indurated, dark blue shale with *Cardioceras*	1	0
Dolerite Sill	3	0
a. Indurated, dark blue shale with belemnites	4	0

The section recorded above is seen in the beach between high-and low-water marks but higher beds are exposed in a small cliff just above high-water mark at Point 3. They are as follows:

Oxford Clay

	ft	in
19. Dark blue shale	15	0
18. Irregular and impersistent grey cementstone		3
17. Dark blue shale	4	0
16. Hard grey cementstone weathering yellow	3 in to	9
15. Dark blue shale	9	0
14. Dark blue shale with abundant *Cardioceras, Pleuromya uniformis* (J. Sowerby), *P.* cf. *alduini* (Brongniart), *Parallellodon aemulum* (Phillips) *Oxytoma sp., Camptonectes sp.,* and phosphatic concretions	15	0

At the southern end of this section the beds are disturbed by a small fault and a few yards to the south of this a larger fault occupied by a dyke brings the Upper Oxford Clay on its northern side against Middle Corallian shales on the south. There must be 5-6 ft of strata unexposed between the top of the Staffin Bay beach section and the beds seen in the small cliff.

Owing to the disturbed nature of the section at Point 3 systematic collecting is difficult and it was not found possible to establish all the zones found to be present to the north at Point 5. The general sequence however is identical at the two localities.

From the base of the blue shales (Bed 7, Staffin Bay section) *Kosmoceras* (*Gulielmites*) aff. *conlaxatum* S. S. Buckman was collected but is not at all common and 16 ft higher *Kosmoceras* (*Gulielmites*) *sp.*, *Pseudocadoceras* (*Longaeviceras?*) *sp.* and *Hibolites hastatus* (Blainville) were found. Thus approximately the lowest 20 ft of these shales may be regarded as belonging to the *K. jason* Zone.

A few feet above the two cementstones (i.e. at the base of Bed 11, Staffin Bay section) *Quenstedtoceras* (*Prorsiceras*), cf. *gregarium* (Leckenby), *Eboraciceras* cf. *cadiforme* Buckman and the outer whorls of large Kosmocerates such as are found at Tidmoor Point Weymouth, indicate the presence of the *Q. lamberti* Zone which cannot however occupy more than a few feet of shale, for 6 ft above the upper of the two cementstones the *Q. maria* Zone (*Q. vertumnus* Subzone) is indicated by the presence of *Quenstedtoceras* (*Vertumniceras*) *vertumnus* (Leckenby), *Quenstedtoceras* cf. *lamberti* (J. Sowerby) Lahusen pars., and a doubtful *Poculisphinctes sp. Cardioceras* cf. *praecordatum* (R. Douvillé) occurs a few feet above the red weathering cementstone (Bed 12, Staffin Bay section) so that the lower part of Bed 13 is in the *C. praecordatum* Subzone of the *Q. mariae* Zone. The upper half of Bed 13 near the top of the beach section is crowded with ammonites mainly Cardiocerates. The following forms have been collected here:

Cardioceras cf. *cardia* S. S. Buckman, *C. spp.* (*cardia* group), *C.* cf. *costicardia* S. S. Buckman, *C.* cf. *cordatum* auctorum, *C.* cf *costellatum* S. S. Buckman, *C. spp.* (*costellatum* group), *C.* cf. *excavatum* Lahusen *non* Sowerby?, *C. spp.* (*nikitinianum* group), *C. spp.* (*praecordatum* group), *C.* cf. *rouillieri* (Nikitin) Lahusen, *Peltoceratoides* aff. *williamsoni* (Phillips), *Peltoceratoides sp., Perisphinctes* (*Pachyplanulites?*) *sp.*, (*Properisphinctes?*) cf. *indogermanus* Boden *non* Waagen, *Cylindroteuthis sp.*, and *Pachyteuthis* aff. *panderiana* (d'Orbigny) auctorum.

This fauna is taken to indicate the *C. cardia* Subzone of the *C. cordatum* Zone.

The higher beds in the cliff at Point 3 (Beds 14-19) yielded a fauna indicating the upper *C. cordatum* Zone (*C. excavatum* Subzone): *Cardioceras* (*Scoticardioceras?*) cf. *excavatum* auctorum, *C.* sp. (*cordatum* group), *C.* cf. *cordatum* (J. Sowerby), *C.* cf. *schellwieni?* Boden, *C. sp.* (*schellwieni* group), *C.* cf. *papiloniense* Boden.

This section of the Oxford Clay can be traced northwards along the beach to Point 4 where the beds are even more badly shattered by faulting and indurated by dykes. At the two most northerly dykes at Point 4 higher beds are exposed than any at Point 3. Seawards and slightly north of these dykes about 60 ft of Oxford Clay is seen in the beach at low tide. Almost the whole of the *C. cordatum* Zone is exposed and though the ammonites are not particularly well preserved the two subzones *C. cardia* and *C. excavatum* can be recognized. The *C. cardia* Subzone, extending from a cementstone at low-water mark upwards through 30 ft of strata contains a finely ribbed form of *Cardioceras* (*Scarburgiceras*) *praecordatum* (R. Douvillé), *C.* cf. *cardia* S. S. Buckman and Cardiocerates probably of the *costellatum–anacanthum* group. Above, the *C. excavatum* sub-zone, 20-30 ft thick, contains an evolute variety of *Cardioceras* (*Scoticardioceras ?*) cf. *excavatum* (J. Sowerby) and several Cardiocerates which appear to be the inner whorls of forms belonging to the *excavatum* group.

Northwards of Point 4 the Oxford Clay extends along the beach to Point 5 where very good sections are to be seen (see section p. 52). As at Point 3 the lowest 12 in of blue shale contains a Kosmocerate fauna indicative of the *K. jason* Zone. The ammonites are badly preserved but may be referred to *Kosmoceras* (*Gulielmites*) *sp.* Immediately below the two cementstones (i.e. at the top of Bed 18, section p. 52) the shales contain *Kosmoceras* (*Gulielmites*) *sp.* and *Kosmoceras* (*Spinikosmoceras ?*) *sp.* which suggest the presence of the Zone of *K. castor* and *K. pollux*. The shales immediately above the two cementstones probably belong to the *Peltoceras athleta* Zone for they contain poorly preserved *Kosmoceras sp.* (cf. *proniae* var. *crassa* R. Douvillé). Three to four feet higher the *Q. lamberti* Zone is indicated by *Quenstedtoceras sp.*, *Kosmoceras* cf. *spinosum* (J. de C. Sowerby = *ornatum* R. Douvillé) and *Eboraciceras sp.* The zones of *K. castor* and *K. pollux*, *P. athleta* and *Q. lamberti* are very poorly developed and together occupy less than 15 ft of shale.

From 7 ft above the upper of the two cementstones, for a thickness of 22 ft, the shales contain ammonites of the *Q. mariae* Zone. Here the *Q. vertumnus* Subzone is obscure, containing only indeterminate *Quenstedtoceras* but the upper 18 ft have yielded *Cardioceras* (*Scarburgiceras*) *spp.* (*praecordatum* group), *Quenstedtoceras. sp.* and *Cylindroteuthis oweni* (Pratt) and therefore belong to the *C. praecordatum* Subzone.

The top of the *Q. mariae* Zone may be conveniently taken at a 4 to 5-in cementstone (Bed 25, section p. 52), above which for the next 30 ft the shales contain a fauna indicative of the *C. cardia* Subzone (lower *C. cordatum* Zone) i.e. *Cardioceras* cf. *costellatum* S. S. Buckman, *Cardioceras sp.* (*costellatum* group), *Cardioceras sp.* (*praecordatum* group) and *Peltoceratoides* aff. *williamsoni* (Phillips).

At the northern end of the Point 5 section the uppermost beds of the Oxford Clay are exposed, i.e. the *C. excavatum* Subzone (upper *C. cordatum* Zone). The ammonites are badly preserved but the following forms can be recognized:
Cardioceras aff. costellatum S. S. Buckman, *C.* cf. *cordatum* (J. Sowerby), *C.* cf. *excavatum* (Sowerby) Boden *pars.*, *C. sp.* (*excavatum* group), *C.* cf. *nikitinianum* (Lahusen) Boden, and *C.* cf. *papiloniense ?*Boden.

A small exposure a few yards inland from High Water Mark at Point 8 [467723], has yielded ammonites indicative of the uppermost Oxford Clay. They are badly preserved Cardiocerates probably of the *C. excavatum* group.

At the seaward end of a small burn entering the south-west corner of Staffin Bay between Glashvin and Digg, blue-grey shales are exposed which contain obscure Cardiocerates with *Pholadomya sp.* and *Terebratula sp.* Apart from these there are no inland exposures of undoubted Oxford Clay but a small patch of blue clay 300 yd N.E. of the cross-roads at Brogaig may belong to this division. The lowest 5 ft of drift in Brogaig Burn north of the main road contain pebbles of shale with Cardioceratid and Perisphinctid fragments and belemnites so that this stream probably flows over Oxford Clay before it descends to the raised beach.

Where Lon a' Mhuilinn joins Lon Glas and turns to flow northwards, is a small exposure of grey shale in the east bank of the stream in which a fragment of belemnite was found. This is probably an inclusion of Oxford Clay in the sill which is here transgressing upwards.

Bryce (1873, p. 332) thought that Oxford Clay was present at Duntulm but a careful search of this neighbourhood has so far failed to find any trace of it.

Oxford Clay is almost certain to be present on the western side of the valley running from Lincro to Knockhoe according to the fossils recorded by Murchison from the canal cut to drain Loch Chaluim Chille (see p. 54), but it is not now exposed.

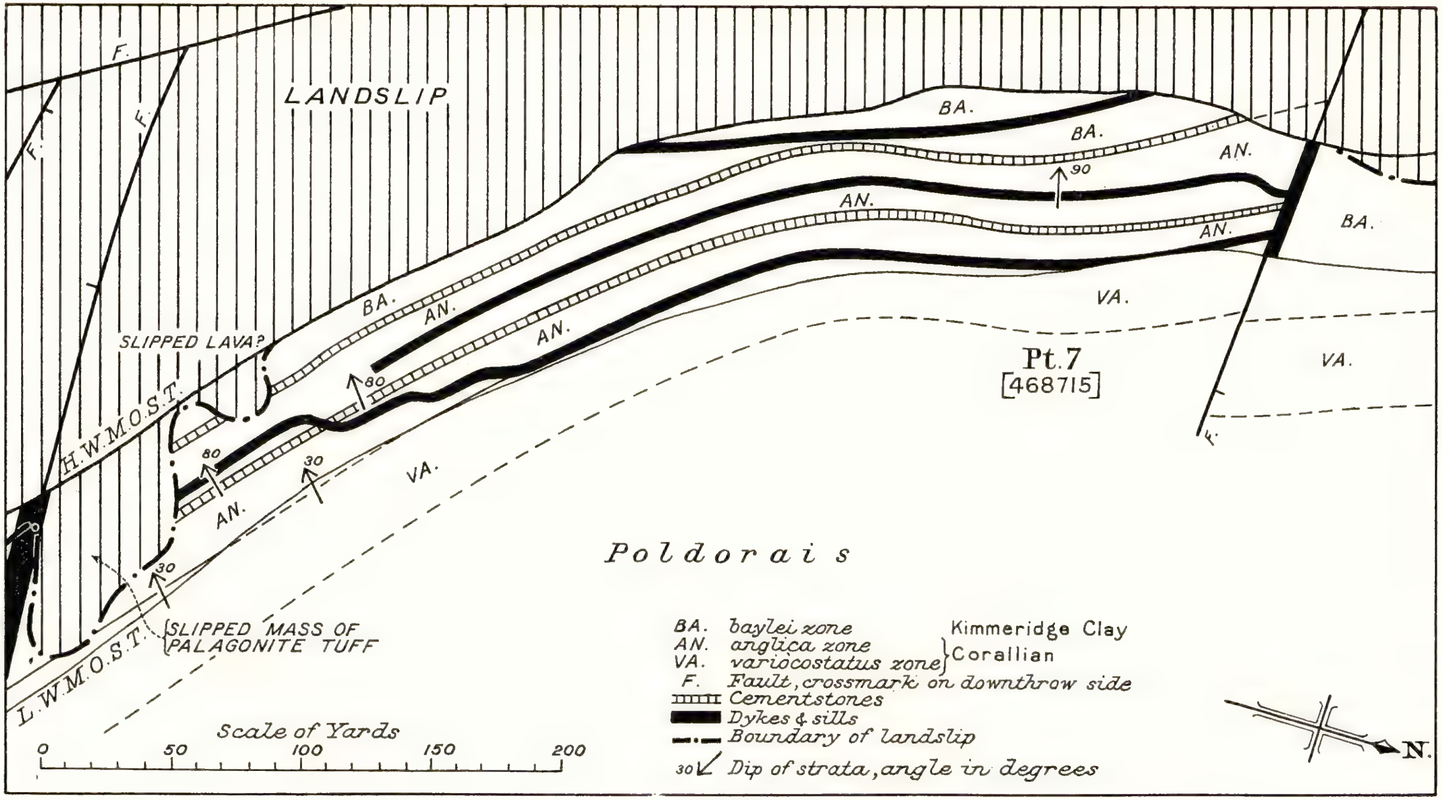


FIG. 11. *Map of Jurassic strata in Staffin Bay, coast south-east of Flodigarry Hotel. Grid references in square brackets*

Blue shale in the screes below the lava scarp south of Totscore probably indicate the presence of Oxford Clay under the superficial deposits.

CORALLIAN

The Corallian beds in Skye are exceptional in that they consist entirely of blue shales with exactly the same lithology as the Oxford Clay below and the Kimmeridge Clay above. As exposed in Staffin Bay the Corallian shales are 140 ft thick and have been divided into the following ammonite zones:

Upper Corallian. *Ringsteadia anglica* Zone
Middle Corallian. *Perisphinctes variocostatus* Zone
Lower Corallian. *Cardioceras cawtonense* Zone

(i) Zone of *Cardioceras cawtonense.*

The lowest 40 ft of the Corallian contains a Cardiocerate fauna and is exposed for some distance south of Point 1 [474694], and north of Point 4 [473701], Staffin Bay. The Zone is poorly exposed and the ammonites are badly preserved but the fauna certainly includes a large number of Cardiocerates which can be referred to *C. cawtonense* (Blake), and *C. maltonense* (Young and Bird), together with *Cardioceras* (*Cawtoniceras*) aff. *blakei* Spath, and *C.* (*Cawtoniceras*) cf. *zietini* (Rouilier) auctorum. Correlation is suggested with the Headington Shell Bed and the lowest 18 ft of the Ampthill Clay at Gamlingay.

(ii) Zone of *Perisphinctes variocostatus.*

The middle Corallian consists of 40 ft of shales exposed at Points 1 [474694], 2 [473696], 3 [473698] and 7 [468715] (Fig. 11) in Staffin Bay and at Flodigarry. The Cardiocerate fauna of the zone below has been succeeded by abundant Amoebocerates such as *A. alternans*, and forms like *A. serratum* (J. Sowerby), *A. marchense* Spath, *A. vagum* Ilovaisky, and Perisphinctids comparable with *P. variocostatus* auctorum, and *P. dichotomum* (S. S. Buckman). These beds are probably the equivalent of the Middle Ampthill Clay and the *Trigonia* Beds of Dorset.

(iii) Zone of *Ringsteadia anglica.*

The uppermost 50 ft of the Corallian exposed in Staffin Bay at Points 1, 2 and 7 is referred to the *R. anglica* Zone. Ammonites are very abundant and consist predominantly of Amoebocerates.

The shales contain numerous individuals of *Amoeboceras* (*Prionodoceras*) *serratum* (J. Sowerby), *A.* (*Prionodoceras*) aff. *serratum* (J. Sowerby), *A.* (*P.*) *alternans* of Russian authors, *A.* (*P.*) cf. *alternans* (Nikitin) and *A.* (*P.*) cf. *excentricum* (S. S. Buckman), with an occasional *Ringsteadea sp.*, *Pictonia sp.* and *Prorasenia sp.* (*witteana* group).

DETAILS

Corallian shales are extensively if not well exposed on the shores of Staffin Bay. At the boat-slip south of Point 1 shales of the *C. cawtonense* Zone are faulted against Mottled Clays. The strike is here north-east, parallel to the direction of the fault but as the beds approach Point 1 they swing round parallel to the coast-line, bend round the irregular intrusive mass of dolerite at Point 1 and continue northwards to within a few yards of Point 3. A very large boulder on the south side of the boat-slip stands on *C. cawtonense* shales. From here the following fossils have been obtained: *Cardioceras* (*Cawtoniceras?*) *sp.*, *Perisphinctes* (*Dichotomosphinctes?*) *sp.*, *C.* (*Cawtoniceras?*) cf. *zietini* (Rouillier) auctorum, *Gryphaea dilatata* auctorum, *Parallelodon* cf. *aemulum* (Phillips), *Pleuromya alduini* (Brongniart), *Pholadomya sp.*

Nearer Point 1 higher beds are exposed and though somewhat disturbed and altered by the intrusion, the *P. variocostatus* and *R. anglica* zones can be recognized. Shales belonging to the former zone are seen near low-water mark and contain: *Amoeboceras* (*Prionodoceras*) *alternans* (Nikitin) and *A.* (*P.*) *marchense* Spath. Near the seaward margin of the storm-beach shales with *Amoeboceras* (*Prionodoceras*) *spp.* of the *ogivale–marchense* group and forms suggestive of *A.* (*P.*) *semicoelatum* Spath indicate the lower part of the *R. anglica* Zone.

Burnt shales exposed on the footpath over the cliff spur at Point 1 are probably Kimmeridge in age.

In the beach at Point 2 the upper half of the Corallian is well exposed.

Section in the beach immediately north of Point 2 [473696], *Staffin Bay*

Dolerite sill	ft	in
P. baylei Zone (Kimmeridge Clay)		
18. Dark grey shale	2 ft to 3	0
17. Grey cementstone	1	0
16. Dark grey shale	4	0
15. Band of calcareous concretions		0 to 12
14. Dark grey shale	3	0
13. Band of calcareous concretions		0 to 12
12. Dark grey shale	6	0
11. Grey cementstone	1	0
10. Dark grey shale with *Pictonia*	3	0
R. anglica Zone. Corallian		
9. Grey shale	24	0
8. Dark grey shale with *Amoeboceras*	3	0
7. Grey cementstone		0 to 12
6. Dark grey shale with *Amoeboceras*	15	0
Dolerite sill		
5. Dark grey shale with *Amoeboceras*	3	0
4. Dark grey shale	11	0
P. variocostatus Zone. Corallian		
3. Dark grey shale	11	0
2. Dark grey shale with *Amoeboceras* and *Goniomya literata* (J. Sowerby)	5	0
Dolerite sill	2	6
1. Dark grey shale with *Amoeboceras*	8	0

The lowest beds, which are only exposed at very low tides, contain a rich ammonite fauna indicative of the *P. variocostatus* Zone. Below a 2 ft 6 in leaf of sill the following were collected: *Amoeboceras* (*Prionodoceras*) *alternans* auctorum (Nikitin 1916, pars) *A.* (*P.*) *alternans* of Russian authors (= aff. *freboldi* Spath) *A.* (*P.*) *alternans* Sokolov 1912, *A.* (*P.*) aff. *marchense* Spath, *A.* (*P.*) cf. *marchense* Spath, *A.* (*P.*) *sp.* (*serratum* group).

From the 5 ft of shales above the sill an abundant fauna was obtained: *Amoeboceras* (*Prionodoceras*) *alternans* Ilovaisky 1904 (= aff. *freboldi* Spath), *A.* (*P.*) aff.

alternans of Russian authors, (trans. to *serratum* group), *A.* (*P.*) aff. *marchense* Spath, *A.* (*P.*) *sp.* (*prionodus–excenticus* group), *A.* (*P.*) cf. *serratum* (J. Sowerby), *A.* (*P.*) aff. *serratum* (J. Sowerby), *Perisphinctes sp.* (*biplex* group, cf. *variocostatus* auctorum), *P.* cf. *dichotomus* (S. S. Buckman), *P. sp.*

Bed 5, 22 ft higher, contains a fauna clearly indicating the *R. anglica* Zone: *Amoeboceras* (*Prionodoceras*) aff. *alternans* of Russian authors (= *regulare* Spath), *A.* (*P.*) cf. *alternans* of Russian authors (= *regulare* Spath), *A.* (*P.*) aff. *semicoelatum* Spath, *A.* (*P.*) *sp.* (*serratum* group).

Between an 8-in sill and the cementstone 15 ft above (Bed 6) the shales yielded: *Amoeboceras* (*Prionodoceras*) *sp. juv.* (inner whorls of *A. prionodes* group) and *Pictonia sp.* The following species were obtained from above the cementstone (Bed 8): *Amoeboceras* (*Prionodoceras*) aff. *alternans* of Russian authors (= aff. *freboldi* Spath), *A.* (*P*). cf. *alternans* of Russian authors, *A.* (*P.*) cf. *freboldi* Spath, *A.* (*P.*) *alternans* of Russian authors (= aff. *regulare* Spath), *A.* (*P.*) *spp.* (inner whorls of *regulare*, *freboldi*, *excentricum* etc.), *A.* (*P.*) *sp. juv.* (inner whorls of forms of *regulare–excentricum* group).

In dark grey shales immediately below a cementstone (Bed 10) the basal fauna of the Kimmeridge Clay (*P. baylei* Zone) is represented by *Pictonia* cf. *cymodoce* Salfeld and *Pictonia sp.* (*normandiana–latecostata* group). The sequence here (see section p. 66) agrees very closely with that at Kildorais (Point 7).

From Point 2 the Corallian shales cross a small bay, on the north side of which they can be seen faulted against Oxford Clay by a N.N.W. fault, the site of which is marked by a large dyke.

North of Point 4 [473701] two large dykes exposed in the storm-beach penetrate lower Corallian shales. The beds are badly burnt by the dykes; thus the fossils are poorly preserved so that specific determination of individuals is difficult. There is no doubt, however, that the fauna includes *Cardioceras* (*Cawtoniceras*) aff. *blakei* Spath, *C. cawtonense* (Blake) and *C.*, *maltonense* (Young and Bird) with *Pachyteuthis* aff. *panderiana* (d'Orbigny) auctorum, *Lima* (*Plagiostoma*) *laeviuscula* J. Sowerby, *Inoceramus sp.* (near *nitescens* Arkell), *Gryphaea sp.*, *Perampliata ampliata* (Phillips), and *Parallelodon* (*Beushausenia*) cf. *aemulum* (Phillips). Out of the large number of specimens collected, the two species *Cardioceras cawtonense* and *C. maltonense* were so markedly predominant that these lowest beds of the Corallian have been separated off as the zone of *C. cawtonense* (= *perarmatum* Zone of Spath 1933, table ii, p. 872).

A small triangular mass of Corallian of the *R. anglica* Zone is faulted in just south of Point 6 [470712]. In the few feet of shale exposed *Amoeboceras* (*Prionodoceras*) cf. *alternans* of Russian authors and *A.* (*P.*) *sp.* (*ogivale–marchense* group) were obtained.

Between Points 6 and 7 [468715] the whole of the *R. anglica* Zone and the basal beds of the Kimmeridge Clay are well exposed in the beach. A typical section is that seen a little way south of Kildorais (Point 7).

Section in beach at Kildorais, Point 7 [468715], *Staffin Bay*

P. baylei Zone (Kimmeridge Clay)	ft	in
15. Dark blue-grey shale with several bands of calcareous concretions (septaria). *Pictonia*, *Amoeboceras*, *Astarte* etc.	35	0
14. Grey cementstone	0 to 1	4
13. Dark blue-grey shale with *Amoeboceras*, *Pictonia* and *Astarte subdepressa* Blake and Hudleston	4	0
12. Grey cementstone	0 to 1	0
11. Dark blue-grey shale with *Prorasenia*, *Pictonia*, *Goniomya literata* (J. Sowerby), *Oxytoma expansa* (Phillips), *Pholadomya* cf. *aequalis* (J. de C. Sowerby)	2	0

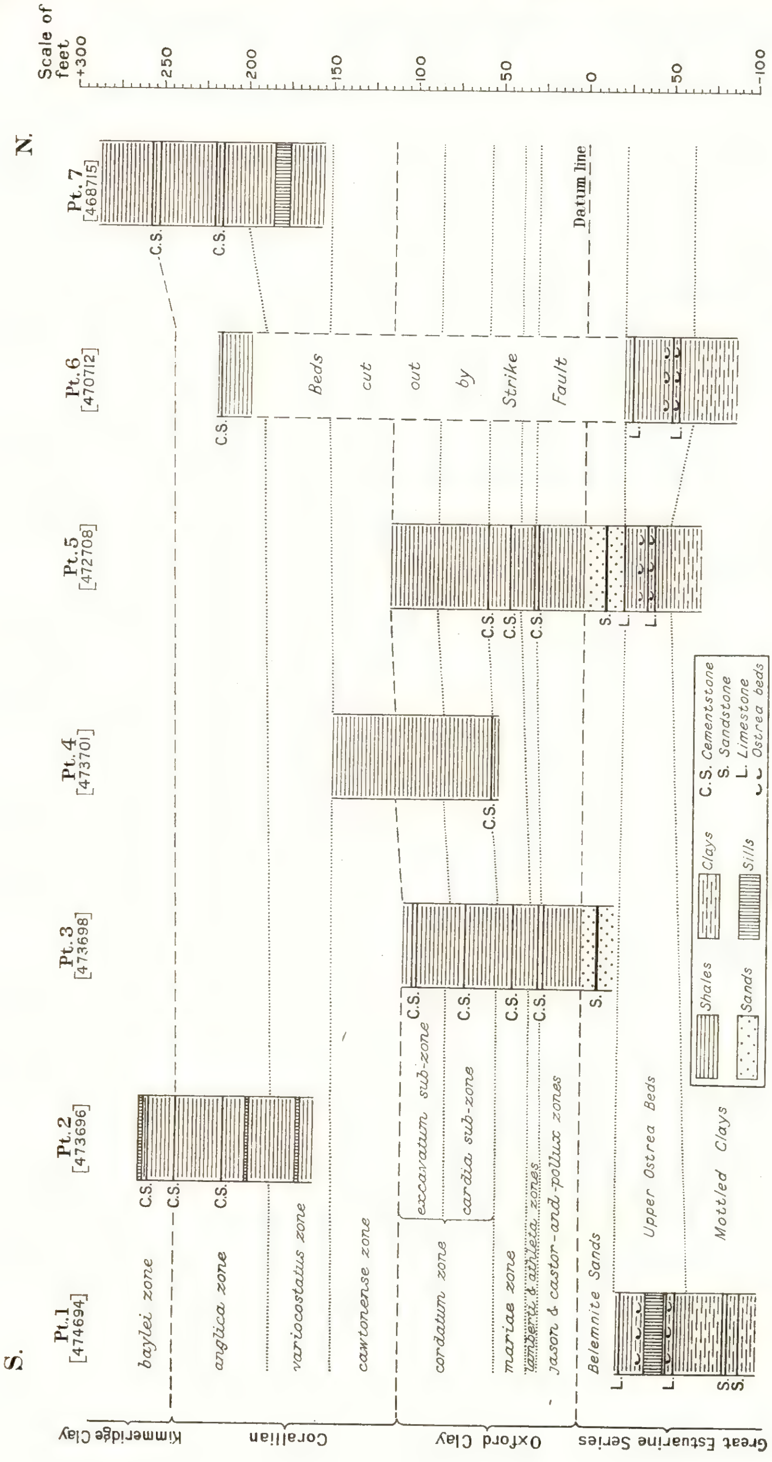


FIG. 12. *Correlation of the Jurassic strata exposed in Staffin Bay. Grid references in square brackets*

R. anglica Zone (Corallian)	ft	in
10. Dark blue-grey shale with *Amoeboceras, Prorasenia, Pleuromya alduini* (Brongniart), *Oxytoma expansa* (Phillips) in lowest 5 ft	18	0
9. Band of calcareous concretions		0 to 3
8. Dark blue-grey shale	10	0
7. Dark blue-grey shales with *Amoeboceras* and *Ringsteadia*	5	0
6. Grey cementstone	0 to 3	0
5. Dark blue-grey shale	6 ft to 7	0
4. Grey cementstone		6 in to 12
3. Dark blue-grey shale	13	0
P. variocostatus Zone (Corallian)		
2. Dark grey shale	17	0
Dolerite sill	10	0
1. Dark blue-grey shale with *Amoeboceras*	20	0

Beds 1 and 2 of this section are exposed near low water-mark and represent the upper part of the *P. variocostatus* Zone. They contain the following ammonites: *Amoeboceras* (*Prionodoceras*) aff. *alternans* (Nikitin) (= aff. *regulare* Spath), *A.* (*P*) cf. *marchense* Spath, *A.* (*P.*) cf. *vagum* (Ilovaisky), *A.* (*P.*) aff. *serratum* J. Sowerby *sp.* (cf. Spath 1935, p. 74).

Above the lower pair of cementstones (Bed 7) the shales contain a fauna indicative of the lower part of the *R. anglica* Zone: *Amoeboceras* (*Pionodoceras*) cf. *alternans* (Nikitin) of Russian authors, *A.* (*P.*) cf. *excentricum* (S. S. Buckman), *A.* (*P.*) *sp.* (*prionodes* group), *A.* (*P.*) *serratum* (J. Sowerby), *A.* (*P.*) aff. *serratum* (J. Sowerby), *A.* (*P.*) *sp.* (*serratum* group), *Ringsteadia sp.* (cf. Spath, 1935, pl. 9, fig. 2).

In the shales 3-5 ft above the band of calcareous concretions (Bed 10) are ammonites indicating the middle of the *R. anglica* Zone: *Amoeboceras* (*Prionodoceras*) *sp.* (cf. *alternans* Nikitin = *regulare* Spath), *A.* (*P.*) aff. *serratum* (J. Sowerby), *A.* (*P.*) *sp.* (*serratum* group), *Pictonia ?, Prorasenia sp.* (*witteana* group).

Immediately below the two upper cementstones (upper two feet of Bed 11) the shales contain a fauna indicating the *P. baylei* Zone of the Kimmeridge Clay.

In the lower part of this section the dip is westwards at 30-40° but the beds turn over rapidly and at the top of the section are practically vertical.

At Point 7 an E.N.E. fault, the position of which is marked by a dyke, brings Corallian on the southern side against Kimmeridge Clay to the north.

Between Points 7 and 8 [467723] several small leaves of sill cross the beach usually with a little burnt shale on either side. Some of this shale must be of Corallian age but the fossils are altered beyond recognition.

Inland the exposures of Corallian shale are few and poor. In the grounds of Flodigarry Hotel is a small quarry showing a lenticle of indurated shale in dolerite sill. The beds contain fragmentary and much altered ammonites referable to *Amoeboceras* (*Prionodoceras*) aff. *serratum* (J. Sowerby) and indeterminate Perisphinctids and therefore probably belong to the *R. anglica* Zone.

In a small roadside quarry west of Flodigarry Hotel and across the main road are several small exposures of much weathered and altered shale. Some of these beds have yielded a fauna which suggests a horizon not met with elsewhere in North Skye, i.e. the *A. alternans* Zone of Spath (1935, p. 74), which in the zonal scheme here adopted would be at the base of the *P. variocostatus* Zone or at the top of the *C. cawtonense* Zone. This fauna consists of: *Amoeboceras sp.* (*alternans* group), *A.* cf. *tuberculato–alternans* (Nikitin), Perisphinctid, *Pictonia ?, Prorasenia ? sp.* (*witteana* group), *Ringsteadia ?, Astarte sp., Lima* (*Plagiostoma*) *sp., Nucula ?, Oxytoma sp.* and *Pholadomya sp.*

The dark shales exposed in the north-west side of a cart road 250 yd S.W. of Kilmaruy burial ground north of Brogaig Burn are probably Corallian in age but are too badly weathered and fragmentary to yield fossils.

Corallian shales do not appear to be exposed north of Flodigarry or on the west side of the Trotternish peninsula, north of Uig Bay.

Near Uig uppermost Corallian Beds are exposed near a small waterfall in Lon an t-Sratha at Balnaknock at the eastern end of the River Conon inlier. About 15 ft of shales contain abundant examples of *Amoeboceras* (*Prionodoceras*) *sp. juv.* These appear to be the inner whorls of *A. excentricum*, *A. serratus* and allies with perhaps also *A.* (*P.*) *alternoides* Spath or *A. freboldi* Spath with the lamellibranch *Pleuromya alduini* (Brongniart). An upper Corallian (*R. anglica* Zone) horizon is indicated. Some 8 ft of shales above are basal Kimmeridge in age (*P. baylei* Zone; p. 71).

On the south side of Ru Idrigal are shales partly incorporated in sill and extensively altered but yielding an ammonite fauna indicative of the *C. excavatum* sub-zone, i.e. *Cardioceras* (*Scoticardioceras*) *excavatum* (J. Sowerby) *C. cordatum* auctorum, *C.* (*Plasmatoceras*) cf. *tenuiostatum* (Nikitin), *C. praecordatum ?*, *C.* cf. *anacanthum-costellatum* S. S. Buckman, Perisphinctid (cf. *P. sayni* de Riaz, Borissjak), *C.* (*Vertebriceras ?*) *sp.*, with the belemnite *Cylindroteuthis oweni* (Pratt) and the lamellibranchs *Pholadomya sp.*, *Camptonectes sp.* and *Parallelodon aemulum* (Phillips).

On the south side of Uig Bay, about ½ mile south of the mouth of the River Conon, beds of this same zone are again seen on the beach. The horizon may be a little different, for although *Cardioceras* (*Scoticardioceras*) *excavatum* is still the dominant form, there are examples of species not seen at Idrigil Point, i.e. *Cardioceras* cf. *persecans* S. S. Buckman and *C.* cf. *caelatum* Pavlow. *C.* cf. *tenuicostatum* (Nikitin) and *C. cordatum* auctorum also occur.

KIMMERIDGE CLAY

Only the lowest beds of the Kimmeridge Clay now remain in North Trotternish. Most of the outcrop is hidden beneath the Quirang landslip or is covered by Tertiary lavas. Much of the shale is indurated and distorted by an upper leaf of the dolerite sill which at the northern end of the syncline transgresses upwards to occupy a position 30-40 ft above the base of the Kimmeridge Clay. Such fragments as still remain have special interest for it is here that the *P. baylei* Zone has what is probably its finest development in Great Britain, occupying a minimum of 20 ft of shale, a thickness which by further collecting might be found to be much greater.

The Kimmeridge Clay follows the Corallian with no change of lithology except that cementstone bands and nodules are rather more abundant than in the beds below. The change of horizon is indicated only by the change in ammonite fauna.

The most complete section is that at Kildorais, Point 7 [468715] in Staffin Bay. Beds 11-15 (Section p. 67) are exposed near high tide-mark and have yielded a rich ammonite fauna consisting predominantly of *Pictonia spp.* with some species of *Amoeboceras.* Belemnites are very abundant. The almost vertical beds owe their inclination to the easterly thrust of the moving landslip. They contain several bands of calcareous concretionary nodules, usually in the form of septaria, and two impersistant cementstones.

In the two feet of shale immediately below the lower cementstone (Bed 11) the following have been collected: *Pictonia* aff. *bigoti* Tornquist, *Pictonia sp.* (cf. *bigoti* Tornquist), *Prorasenia sp.* (*hardyi* group ?), *Prorasenia sp.* (*witteana* group), *Goniomya literata* (J. Sowerby), *Oxytonia expansa* (Phillips) and *Pholadomya* cf. *aequalis* (J. de C. Sowerby).

Between the two cementstones (Bed 13) ammonites are very abundant though badly preserved. From here the following forms were obtained:

Amoeboceras (*Prionodoceras*) cf. *banhini* Ilovaisky *non* Oppel, *A.* (*P.*) cf. *alternans* (Nikitin) auctorum = *regulare* Spath?, *A.* (*Amoebites?*) *sp.*, *Pictonia* cf. *bigoti* Tornquist, *P.* aff. *bigoti*, *P.* cf. *normandiana* (Tornquist), *P.* cf. *parva* Tornquist, *P.* cf. *laticostata* Tornquist, *P.* aff. *laticostata*, *P. sp.* (*laticostata–normandiana* group), *P. sp.* (*normandiana* group) *P.* aff. *baylei* Salfeld, *P.* aff. *costigera* S. S. Buckman, *Prorasenia sp.*, *Astarte subdepressa* Blake and Hudleston.

For 15 ft above the two cementstones (Bed 15) belemnites are abundant and ammonites fairly common but are crushed and difficult to extract. The fauna indicates: *Amoeboceras* (*Amoebites?*) *sp.* (*beaugrandi* (Sauvage) group), *Pictonia* aff. *baylei* Salfeld, *P.* cf. *laticostata*, *P.* cf. *parva*, *Prorasenia sp.*, *Astarte contejeani* de Loriol, *A. subdepressa* Blake and Hudleston, and *Oxytoma expansa* (Phillips).

So far no fossils have been found above this horizon though the shales continue for another 20 ft before disappearing below landslip.

North of the fault at Point 7 [468715], Kimmeridge Clay underlies the beach for some distance but is poorly exposed. At Point 6 [470712], south of a large dyke and beneath a mass of slipped Palagonite Tuff-breccia, a few feet of blue shale are exposed containing obscure ammonites not specifically determinable. They are predominantly *Pictonia* however, which suggests a horizon near the base of the Kimmeridge Clay. Further south at Point 2 [473696], about 20 ft of Kimmeridge Clay are exposed beneath a leaf of sill (Section p. 66). The shale is poorly fossiliferous and much disturbed by the intrusion, but *Pictonia* cf. *cymadoce* Salfeld and *P. sp.* (*normandiana–laticostata* group) are present and indicate a horizon in the *P. baylei* Zone.

Inland a wedge of Kimmeridge Clay is faulted in amongst the Great Estuarine strata exposed in the Kilmaluag River. Three small exposures in the eastern bank below Kendrom show grey shale with an 18-in cementstone. The numerous ammonites collected from the latter include: *Amoeboceras* (*Prionodoceras*) cf. *alternans* Nikitin, *A.* (*P.*) *sp.* (?cf. *bigoti* Tornquist) and *Pictonia spp.* suggesting a horizon in the *P. baylei* Zone.

North-west of Kendrom in the west bank of the river, a small exposure of clay is probably at about the same horizon but appeared to be unfossiliferous.

Shales belonging to the *P. baylei* Zone are also exposed beside a small waterfall at Balnaknock in the Lon an t-Sratha, a tributary of the River Conon. About 25 ft of shale are exposed including a 6-in cementstone. The uppermost 8 ft of this section contain *Amoeboceras* (*Prionodoceras*) *sp.* and *Pictonia* aff. *baylei* (Salfeld); the lower 15 ft represents the upper part of the *R. anglica* Zone. (p. 70).

References

Arkell, W. J. 1933. *The Jurassic System in Great Britain.* Oxford.

—— 1936. The Ammonite zones in the Upper Oxfordian of Oxford. *Quart. J. Geol. Soc.*, **92**, 146-87.

—— 1945. The Zones of the Upper Jurassic of Yorkshire. *Proc. Yorks. Geol. Soc.*, **25**, 339-58.

Bryce, J. 1873. On the Jurassic rocks of Skye and Raasay. *Quart. J. Geol. Soc.*, **29**, 317-51.

Buckman, S. S. 1913. The 'Kelloway Rock' of Scarborough. *Quart. J. Geol. Soc.*, **69**, 152-68.

Davies, A. Morley. 1916. The Zones of the Oxford and Ampthill Clays in Buckinghamshire and Bedfordshire. *Geol. Mag.*, **53**, 395-400.

FORBES, E. 1851. On the Estuary Beds of Oxford Clay at Loch Staffin in Skye. *Quart. J. Geol. Soc.*, **7**, 104-13.

NEAVERSON, E. 1925. The Zones of the Oxford Clay near Peterborough. *Proc. Geol. Assoc.*, **36**, 27-37.

ORBIGNY, A. D'. 1852. *Prodrome de paléontologie stratigraphique universelle.* Paris.

PRINGLE, J. 1930. East Sutherland Field Meeting, *Proc. Geol. Assoc.*, **41**, 74

SPATH, L. F. 1926. Notes on Yorkshire Ammonites, No. 10, *Naturalist*, 321-6.

—— 1933. Revision of the Jurassic cephalopod fauna of Kachh, pt. 4. *Palaeont. Indica*, **2**, 9.

—— 1935. The Upper Jurassic Invertebrate Faunas of Cape Leslie, Milne Land. I. Oxfordian and Lower Kimmeridgian. *Meddel. om Grønland*, **99**, 1-82.

Chapter V

TERTIARY SEDIMENTS

PALAGONITE TUFFS

IN NORTHERN Skye the earliest volcanic activity of which there is any record resulted in the formation of basic tuffs. These consist of volcanic dust, 'ashes', lapilli and bombs ejected with explosive violence from the vent and deposited in shallow lakes lying on a peneplaned surface of Jurassic rocks. That they were laid down under water is clear, for they are closely associated with shales and flagstones which are crowded with plant debris and the tuffs themselves are largely composed of sideromelane (super-cooled glass) and include some typical pillow lavas and globe-breccias. They are similar to the tuffs of the Palagonite Formation of Iceland (Wilson, 1937, pp. 77-8; Anderson, 1949, p. 785).

The Palagonite Tuffs are brown and yellow deposits composed of (i) angular fragments of pale-brown translucent glass (sideromelane) carrying microlites of plagioclase and augite with occasional small olivine crystals; (ii) the sideromelane fragments altered to a pale green cryptocrystalline substance 'palagonite'. The alteration spreads from the margins and cracks of the larger fragments whereas smaller fragments may be entirely converted into a chloritic material; (iii) fragments of opaque black vitreous slag (Tyrrell, 1949). Included in these tuffs are: (a) thin irregular lava flows of limited extent, very vesicular, often showing pipe amygdales several inches in length. (b) loose, roughly spherical masses of lava with very vesicular centres and a tachylitic crust, the vesicles frequently arranged in concentric layers. (c) smaller globular masses of lava, some of which have the characteristic appearance of 'bombs'. (d) still smaller rounded fragments of vesicular basalt with a tachylitic crust, i.e. lapilli.

The lava flows, in particular those seen in the tuffs just north-east of Portree, frequently exhibit typical pillow structure. Quite apart from the associated planty sediments, the conchoidal fracture (*Bogen* or *Aschenstruktur*), and the cryptocrystalline nature of the smaller basalt fragments, and the vesicular globular and pillowy nature of the larger masses clearly indicate deposition in water.

The formation of Palagonite Tuffs very similar to those in Skye has been discussed by Peacock (1926), Nielson and Noe-Nygaard (1936) and Noe-Nygaard (1936, 1939, 1940), who claim that the Icelandic Palagonites were formed under the ice-cap which accounts for the drastic chilling shown by the fragments composing these tuffs. But Nielson and Noe-Nygaard (1936) have shown that features characteristic of modern sub-aerial accumulations, i.e. deflation surfaces with hamada formation, solifluxion phenomena with desert pavements and stone polygons, and surfaces with dessication cracks are present within the Palagonite Formation. Moreover the palagonite tuffs of the Snake River Plateau of Columbia, like those of Skye, cannot have been formed under glacial conditions (see Peacock and Fuller 1928, Fuller 1931). The essential factors required to produce palagonite tuffs of the type described above are likely to have been a very fluid lava extruded into water. The rapid chilling of the basalt combined with the explosive generation of steam would probably be sufficient to shatter it into the glassy shards so typical of the deposit. The extensive surfaces exposed to alteration would accelerate the breakdown into chlorite. It is possible, as Peacock has suggested, that the presence of hot springs or volcanic gases may be important factors in the conversion of sideromelane into palagonite, or in the case of the Skye deposits the warm climate and the heating up of the shallow lakes in which they were deposited by prolonged eruption.

DETAILS

The most complete section of the Palagonite Tuffs in North Skye is that exposed in the sea-cliff below Craig Ulatota. Here the lowest portion is a pale greenish-brown sandstone with wind-rounded quartz grains overlain by some 70 ft of coarsely fragmented tuff with abundant olivine crystals. A thin imperistent porphyritic olivine-basalt lava flow, up to 5 ft in thickness, follows, overlain by 30-40 ft of brown vitreous tuff containing plant fragments.

Northwards, the fragmental portion of the tuffs increases until at Fuirnean it is about 120 ft in thickness. Here it contains numerous bombs, some of large size, and lava 'globes'.

In a tributary of Lon Druiseach, ½ mile west of the cliff top, the following section is exposed:

Section in Gully on south side of Lon Druiseach, 950 *yd east of the road,* 2½ *ml. N.W. of Portree*

	ft	in
Palagonite Tuffs:		
5. Basalt lava; pipe amygdales in base		
4. Palagonite tuff with pillow lavas	22	0
3. Thin lava flow with pipe amygdales		9
2. Thin bedded, brown tuff	2	4
1. Hard, olive-green tuff		2
Great Estuarine Series:		
Soft sandstone with calcareous bands	14	0

The olive-green beds at the base of the tuffs contain poorly preserved plant fragments, amongst which the late W. N. Edwards identified *Ginkgo* (probably *G. gardneri* Florin), a possible *Equisetum*, an obscure conifer twig and a number of indeterminate dicotyledonous leaves. A fragment of wood 6 ft long by 8 in wide was found in Bed 4 which Edwards compared with the conifer *Cryptomarites*.

In Wilson's preliminary account (1936, p. 82) five genera of dicotyledons with *Sequoia*, *Ginkgo*, and a grass were reported as from this section and were identified by Professor T. Johnson. Wilson also commented on the abundance of *Ginkgo* in Skye as compared with its rarity at Ardtun. As Starkie Gardner recorded in 1887, *Ginkgo* is in fact abundant at Ardtun. In Skye the dicotyledons are the most abundant fossil plants but Edwards, who examined the same material as Johnson, claimed these to be indeterminate generically.

The Palagonite Tuffs are well exposed in the sea-cliff east of Lon Druiseach particularly between Sithean Bhealaich Chumhaing and Rubha na h-Airde Glaise.

Some 60 ft below the top of the scree-slope, a crystal-vitric tuff is exposed containing automorphic olivines and labradorites in a matrix of clear yellow and dark-brown glass. Above this the tuffs are amygdaloidal and include an impersistent, and in places, columnar basalt. About 30 ft below the top, a sandy mudstone containing angular quartz grains and numerous fragments of glass is interbedded with the tuffs. Above is a yellow-brown, vitric tuff with dark glass shards and a few olivine and labradorite crystals in a lighter coloured, glassy matrix and apparently deposited in or by water. This tuff, about 4 ft thick, weathers into small caves below an overlying pillowy, non-porphyritic tholeiitic basalt with pipe amygdales up to 3 in long filled with stilbite and analcime. The junction of this lava with the flat-bedded, fine-grained tuff below is smooth but highly irregular. Locally it shows small scale ropy structure and similar wrinkled surfaces occur within the lava itself. Irregularly shaped pillows up to several feet across can be seen nearby, sometimes with red bole penetrating between them.

Twelve feet above the first is a second mudstone and over it amygdaloidal lavas and tuffs form the remainder of the section up to the base of the first persistent lava-flow. Both here and in Lon Druiseach the tuffs are in places full of zeolites and amygdaloidal chalcedonic silica.

Tuffs and ashy shales with plant remains cut by a 4-ft dyke are exposed in the gully just west of Bile (Beal) Chapel, S.E. of Torvaig and again in the gorge of the River Chracaig, below a waterfall and just west of Portree Lodge [488439]. Here, 3 to 4 ft of dark ashy shales rich in plant debris are exposed below the first continuous lava flow which is responsible for the low waterfall.

A good section of the upper part of the Palagonite Tuffs may be seen in Camas Ban, Portree Bay, where the tuffs include bombs from 1 to 6 in in diameter. The base of the first continuous lava-flow is well seen; it is vesicular but not noticeably chilled. A wedge of sill thinning from 15 ft to nothing in a distance of 50 ft, has a thick tachylitic margin about 9 in wide. Another wedge of sill in the centre of the bay has well-marked but highly irregular columnar jointing at the contact, the columns being about 6 in in diameter. The plant beds must be present in Camas Ban, though they are no longer exposed, for lignite was once worked here.

Eastwards the tuffs are poorly exposed. At Udairn they contain numerous thin impersistent lava flows some of them exhibiting pillow structure. A little over a mile south of Ben Tianavaig the tuffs are exposed in the sea-cliff. Only a little palagonite is present, instead the section consists mainly of dark greenish, ashy mudstones and coarse agglomerates of basalt fragments. Near the base is a thin band of black shale, above which is sandy mudstone and shale with lenticles of sandstone. The shale contains plant fragments.

At Creagan na Sgalain on the north side of Tianavaig Bay the plant beds are well seen:

Section 400 *yd N. of Creagan na Sgalain*

Palagonite Tuffs	ft	in
7. Carbonaceous shale and coal		
Dolerite sill	40	0
6. Massive bedded sandstone with thin shaly partings	20	0
5. Flaggy beds with plant debris	1	0
4. Thin flaggy beds ¼ in thick		6
3. Carbonaceous shale	6	0
Dolerite sill	20	0
2. Carbonaceous shale	1	0
1. Greenish sandstone	2	0
Inferior Oolite sandstone	15	0

The carbonaceous shale with coal was believed by Lee (1920, p. 56) to be the equivalent of the Oil-Shale which is found at the top of the Inferior Oolite further north. The Oil-Shale however, is cut out by the transgressing lavas north of Portree.

These plant-bearing sediments are seen at intervals in the sea-cliff south of Tianavaig Bay in association with sill as far as Peinchorran. Here the upper part of the tuffs, above a sill, forms a steep bank below the village of Peinchorran but is poorly exposed. Eastwards is a peaty flat formed by the top of the sill which crops out as Torr Mor and Torr Beag, below which the lower part of the Palagonite Tuffs can be seen in the sea-cliff. Immediately under the sill is a thin coal overlying sandy micaceous and carbonaceous shales. Below, and extending to sea-level is white sandstone 60-70 ft thick, thin-bedded, calcareous, and with occasional white quartz pebbles and ironstone nodules.

These beds are faulted back and appear again on the beach just west of the mouth of Allt na Ba Grasion in Loch Sligachan.

Inland the Palagonite Tuffs are usually obscured by scree and landslip. It is evident however that as far north as Staffin and Flodigarry the tuffs are present in considerable thickness for large masses can be seen in the landslip. In the upper reaches of Abhainn Gremiscaig is an interesting section showing coals, once worked, and fireclay in dark brown Palagonite Tuff. Tuff with a plant bed is exposed in the Lealt River ⅔ mile E.S.E. of Baca Ruadh, and 30-40 ft of bedded tuff containing bombs, with a 4-ft red bole on top were seen in the landslip east of Carn Liath. These exposures are in landslip and therefore not *in situ.*

Four miles W.N.W. of the last section the base of the lavas is exposed in Glen Uig. Here Corallian and Kimmeridge Clay shales form an inlier surrounded by lava on all sides. The basal tuffs are to be seen where the River Conon leaves the inlier at Peinchonnich represented by 15 ft of black shales and chocolate-brown clay with feldspar crystals below lava, and 800 yd further west just above the weir Knox recorded the following section:

6.	Lava. The base of the flow is uneven with many included fragments of shale for 4-5 ft, above which it is dark and vesicular and partly rotted. Above a variable thickness of this the lava is a compact, fine-grained basalt.	
5.	Soft shaly beds with thin coaly films	about 1 ft 0 in
4.	Dark brown ashy material with coaly films	about 1 ft 6 in
3.	Grey-green fireclay, sandy and ashy	
2.	Flaggy sandstone	several feet
1.	Basalt lava, vesicular top.	

The lava at the base of this section is probably one of the impersistent flows in the Palagonite Tuff sequence. At one time coal was worked here so that much thicker seams must have been present than those now visible. At Peinvraid on the north-east side of the inlier are black shales and thin ashy and sandy beds with coaly films like those recorded above.

In Vaternish Palagonite Tuffs are exposed at intervals at or near sea-level on both shores of Loch Bay associated with an irregular sill. On the eastern shore the tuffs contain fragments of fossilized wood as at Clach Bhuidh [266549] and at Lower Halista lignite was at one time sufficiently abundant to be worked for fuel. A lenticle of sandstone in lava on the shore ½ mile north-west of Creag nam Bodach, Loch Dunvegan, probably indicates the proximity of the basal tuffs.

That the Palagonite Tuffs include plant-bearing sediments was first noted by Wilson in 1935 about 600 yd due west of the south end of Loch Fada. The exposures are poor but about 30 ft of sediments are present consisting of a well-bedded, black, carbonaceous shale, coaly matter, palagonite tuff and a dark-grey, fine grained, shaly, bed in which the plant remains were found. This rock consists of a dark-brown, indeterminate clayey groundmass in which are embedded numerous grains of quartz, feldspar, and glauconite together with much carbonaceous matter.

Interbasaltic Sediments

Considerable periods of time apparently intervened between the eruptions of individual lava-flows, during which the surfaces were exposed to weathering. Thus, in general the flows are separated by lateritic clays or boles produced by the decomposition of the lava. Much longer time-intervals, however, occurred between the eruptions of the fissures from which the various groups of lavas were extruded, and during these periods soils developed and in some cases a cover of vegetation. The deposits formed during these quiescent interludes were not extensive and probably not continuous. Moreover, the lava field is now much broken up by faulting so that it is a matter of considerable difficulty to relate these deposits to each other and to the episode to which they belong. That some explosive volcanic activity took place during these periods is evident by the accumulation of tuffs and agglomerates accompanying the sediments.

The lens of agglomerate 30 yd long and 4 ft thick on the west side of Lyndale Point and the sandstone in the lavas ½ mile N.W. of Creag nam Bodach in Loch Dunvegan appear to be deposits on the surface of the Vaternish lava group overlain by the porphyritic basalts of the Ramasaig group[1]. This contact has not been seen elsewhere but probably lies below later lavas south of Loch Snizort Beag.

The interval between the Vaternish and Ramasaig groups and the overlying Osdale mugearite-basalt group appears to have been of longer duration and extensive plant-bearing sediments were laid down over much of the area. At the waterfall in the stream running from Suidh 'Fhinn to Sulishadermore, just west of Portree, are shaly sediments baked by a dyke which appear to be in this catagory. A conglomerate of lava pebbles, dark shales and thin coaly beds crops out in the Tungadal River, 1 mile N.E. of Roineval and similar sediments were found about ½ mile N.W. of Meall an Fhuarain. Both these deposits appear to lie between the Vaternish and Osdale groups of lavas.

The interlude between the Ramasaig and Osdale lava groups is separated by trachytic ash with sandstone and shaly sandstone with plants exposed in the Hamra River, Glendale, Duirinish (Fig. 13), in all about 20 ft of sediment.

Three miles to the south-east 25-30 ft of sediments are again exposed in this category in Glen Osdale W.S.W. of Healaval Mhor. Here sandstones and conglomerates and shaly plant beds contain the most extensive and important leaf impressions so far found in any of the Scottish interbasaltic deposits apart from Ardtun. The slabs crowded with leaves are similar to those from Ardtun though on the whole the plants are not so complete or well-preserved. The late Sir A. C. Seward and the late Mr. W. N. Edwards examined this material and, with the exception of an obscure fertile shoot at present indeterminable, referred them all to characteristic Ardtun species belonging to the genera *Quercus*, *Corylus* and *Platanus*.

Some two miles S. E. of Glen Osdale about 10 ft of conglomerates and muddy sandstones are exposed in Forse Burn (Fig. 13) apparently at the same horizon as the two previous localities.

---

[1] For details of the lava groups see p. 81

REFERENCES

ANDERSON, F. W. 1949. Geological Observations in South-eastern and Central Iceland. *Trans. Roy. Soc. Edin.*, **61**, 779-91.

FULLER, R. E. 1931. The Aqueous chilling of basaltic lava on the Columbia River Plateau. *Amer. J. Sci.*, **21**, 281-300.

GARDNER, J. S. 1887. On the Leaf-Beds and Gravels of Ardtun, Carsaig etc., in Mull. *Quart. J. Geol. Soc.*, **43**, 270-300.

LEE, G. W. 1920. The Mesozoic Rocks of Applecross, Raasay and North-East Skye. *Mem. Geol. Surv.*

NIELSON, N. and NOE-NYGAARD, A. 1936. Om den islandske Palagonitformation's Oprindelse. *Saertryk Geog. Tidsskr.*, **39**, 3-36.

NOE-NYGAARD, A. 1936. Material sammensaetningen af sidste Vulkandbrud under Vatnajökull, *Saertryk Nord. Naturf. Helsingfors*, **19**, 420-2.

—— 1939. Sideromelantuf fra Faerøerne. *Medd Dansk Geol. For.*, **9**, 422-5.

—— 1940. Sub-glacial volcanic activity in Ancient and Recent Times. (Studies in the Palagonite-System of Iceland, No. 1). *Folia Geog. Danica*, **1**, 1-67.

PEACOCK, M. A. 1926. The Vulcano-Glacial Palagonite Formation of Iceland. *Geol. Mag.*, **63**, 385-99

—— and FULLER, R. E. 1928. Chlorophaeite, Sideromelane and Palagonite from the Columbia River Plateau. *Amer. Mineral.*, **13**, 370.

WILSON, G. V. 1937. In *Sum. Prog. Geol. Surv.* for 1963, pt. I

Chapter VI

TERTIARY LAVAS

General Account

As in Mull, the Tertiary lavas of Skye are divisible into two suites, a lower consisting primarly of olivine-basalts and an upper in which mugearites are at least as abundant as basalt flows and in which subordinate trachytes appear.

The initial explosive phase which produced the basal palagonite tuffs was followed by a vast outpouring of lava from numerous fissures, mostly situated north of the volcanic centre. The composite lava field gradually built up by these extrusions cannot at its maximum have been much less than 4000 ft thick, for some of the downfaulted remnants approach this thickness and much must have been removed by the severe erosion of the late-Tertiary and Pleistocene periods.

It has long been maintained that the lavas of Skye, in common with those of the north-west volcanic province generally, are but remnants of a vast North Atlantic Plateau which embraced also the lavas of Antrim, Iceland and Greenland. Though it is true to say that the lavas of this hypothetical North Atlantic Plateau are in general of similar basaltic type, there are considerable differences in detail. No two areas have exactly the same sequence of lavas and there are petrological differences in the rocks themselves. Their present day distribution also militates against the theory of a common origin since in every case they are grouped about or near an intrusive centre. Moreover, the isolation of the various plateau remnants would require large-scale faulting, whereas so far as is known, the late-Tertiary faults, though very numerous, are nowhere of very great displacement. The distribution of lava types in Skye suggests that they were extruded from several fissures related to a central volcano. Quite apart from the field evidence the postulate of several rather than one fissure is necessary for, if the observed sequence had been built up by the vertical emplacement of flows, the total thickness of the lava-field would have exceeded 7000 ft and faults of this magnitude would be required to bring about the juxtaposition of early and late flows so frequently seen. There is abundant evidence that the Jurassic floor is nowhere very far below sea-level and the introduction of faults with a displacement of much more than 1000 ft is difficult. Moreover, the several groups into which these Skye lavas have been divided all show thinning away from centres which are assumed to be the sites of their feeders. Thus the lava-pile is thought to have been built up by flows from several fissures operating at different times and in different places, meeting and overlapping along their margins and eventually forming an interleaved series which in any one place need not have exceeded 4000 ft in thickness.

A precise age for the period of volcanic activity in Skye and in the Thulean province generally has not yet been satisfactorily determined. Plant remains found in the basal palagonite tuffs of Skye and in the inter-basaltic sediments of Skye, Mull and Antrim have been thought to suggest a period of eruption not earlier than late Oligocene (Simpson 1951, 1952, 1961). A similar dating is said to be given by the remanent magnetism of the Skye basalts and the gabbros of Skye, Ardnamurchan and Rhum (Khan 1960).

On the other hand, Gardner (1887), Manum (1962), Pflug (1956) and Watts (1962) after examining plant material from the Hebrides, Spitzbergen, Iceland and Ireland respectively have generally agreed on a lower Tertiary, probably Eocene, age for the inter-basaltic sediments. Recent potassium-argon age determinations by Brown and Miller (1963) of the Antrim and Mull basalts indicate an age of about 74 million years for these lavas, from which it can only be concluded that they are Eocene or earlier in age.

In 'The Tertiary Igneous Rocks of Skye', Harker (1904, p. 235) described what he called 'The Great Group of Basic Sills'. He first of all referred to the numerous intrusive sheets in the Jurassic strata first recognized as such by Macculloch (1819) and then claimed that this series of sills is continued upwards in the lava-pile. The evidence of the intrusive nature of these sheets was said to be (a) occasional transgression, (b) intersection of the earlier basic dykes, (c) petrological affinities with the lower sills and differences from the lavas, (d) Harker also noted that these supposed sills thin out and disappear in the neighbourhood of the gabbro and granite intrusions, probably, he suggested because of the destruction of the bedding in the lavas of the metamorphosed belt.

It has become abundantly evident during the mapping of northern Skye that Harker was mistaken and that in general the basic sills did not invade the lavas. The supposed sills are nothing more than the hard, compact centres of the lava-flows, emphasized and distinguished from the amygdaloidal tops and bottoms by subsequent erosion. Apparent transgressions when examined in detail turn out to be due to the irregular nature of amygdaloidal zones, on the one hand or to the disturbing effect of the numerous faults and dyke intrusions. No case has been found in which any dyke has been cut across by the basalts of the lava field. Possibly Harker was here referring to sills in the Jurassic basement which are known to be later than the earliest basic dykes. Since Harker did not refer to a specific example it is impossible to check this statement in the field. Moreover, having assumed the identity of the so-called sills in the lava sequence and the sills in the Jurassic sediments, Harker proceeded to deal with them as a group and it is impossible to discover in many instances the origin of the evidence quoted.

Thus it is necessary to contradict the statement that the petrological affinities of the upper 'sills' is with the lower sills and not with the lavas without examining his evidence in detail. The petrological details given in Chapter VII offer the best evidence in favour of the contradiction.

The apparent thinning and dying out of these 'sills' in the neighbourhood of the major intrusions is simply due to the destruction of bedding and hardening of the lavas by thermal metamorphism.

Since Harker's opinions have great authority and in view of the fact that his conclusions were not only published in Survey memoirs but also incorporated on the published maps of Western Skye (One-inch Minginish (70) Sheet) and Central Skye (One-inch Glenelg (71) Sheet), the lavas of northern Skye were examined with special attention to this question of intrusive sheets being incorporated in them. In every case where a lava succession was examined in detail it was seen to consist of an uninterrupted succession of flows. The massive basalt of the main part of each flow (the 'sill' of Harker) was succeeded by an upper vesicular portion without a plane of division and without any sign of chilling. The tops are almost always reddened and in very many cases had been weathered into a red bole. The bases of the flows are frequently vesicular or brecciated or both. The characteristic step-like features of the lava-field are due to the differential weathering of the softer vesicular portions and the boles and the hard compact centres.

Individual flows are frequently very persistent and can be traced for miles without any appreciable thinning. On the other hand some flows, like that numbered 8 in The Storr Section, are extremely irregular and vary considerably in thickness over a distance of a few yards. The only instances of sheet-like intrusions found in the lavas are (1) an offshoot from the eastern side of a large Allivalite dyke crossing An Cleireach, 3½ miles N.W. of Bracadale, and extending for not more than three-quarters of a mile, (b) three sheets of dolerite cutting across the lavas in Oisgill Bay (Duirinish) at an angle of 30-40°.

In general the highest sill noted was that frequently found in the basal tuff and there is visual evidence in the cliff section some four miles north of Portree that this sill was unable to penetrate the first continuous lava-flow above.

The Skye lavas can be divided into five groups with approximate thickness as follows (Fig. 13):

5. *Osdale Group* 1600 ft
   Alternating Basalt and Mugearite flows
4. *Bracadale Group* 400 ft
   Alternating Mugearite and Trachyte flows
3. *Beinn Totaig Group* 2000 ft
   Alternating Basalt and Mugearite flows. A porphyritic basalt at the top of the Group.
2. *Ramascaig Group* 2500 ft
   Alternating porphyritic and non-porphyritic Basalts, with a mugearite flow over the top of the Group.
1. *Beinn Edra Group* 1000 ft
   Non-porphyritic Basalts with a few porphyritic flows and a mugearite at the top of the Group.

DETAILS

BEINN EDRA GROUP

The fissure from which this group of lavas was extruded must have been located in Trotternish and may be that later occupied by the picrite dykes at Beinn Tuath and Glenuachdarach, having the usual N.N.W. trend. All the lavas of the Trotternish peninsula are thought to have emanated from this vent. The flows probably extended westwards as far as the Vaternish peninsula and southwards beyond Drumuie to Portree, Ben Tianavaig and beyond the southern boundary of the one-inch sheet to Ben Lee. The area they covered coincides roughly with that in which the picrite dykes are found.

The lower lavas of the group are to be seen in the neighbourhood of Uig Bay and the Conon Inlier. They appear to consist entirely of undifferentiated basalts. The group as a whole forms the eastern escarpment of Trotternish extending from Portree to Flodigarry, but the lower flows are mostly hidden beneath scree and landslip. The upper part, capped by a conspicuous mugearitic-basalt with columnar jointing, is well

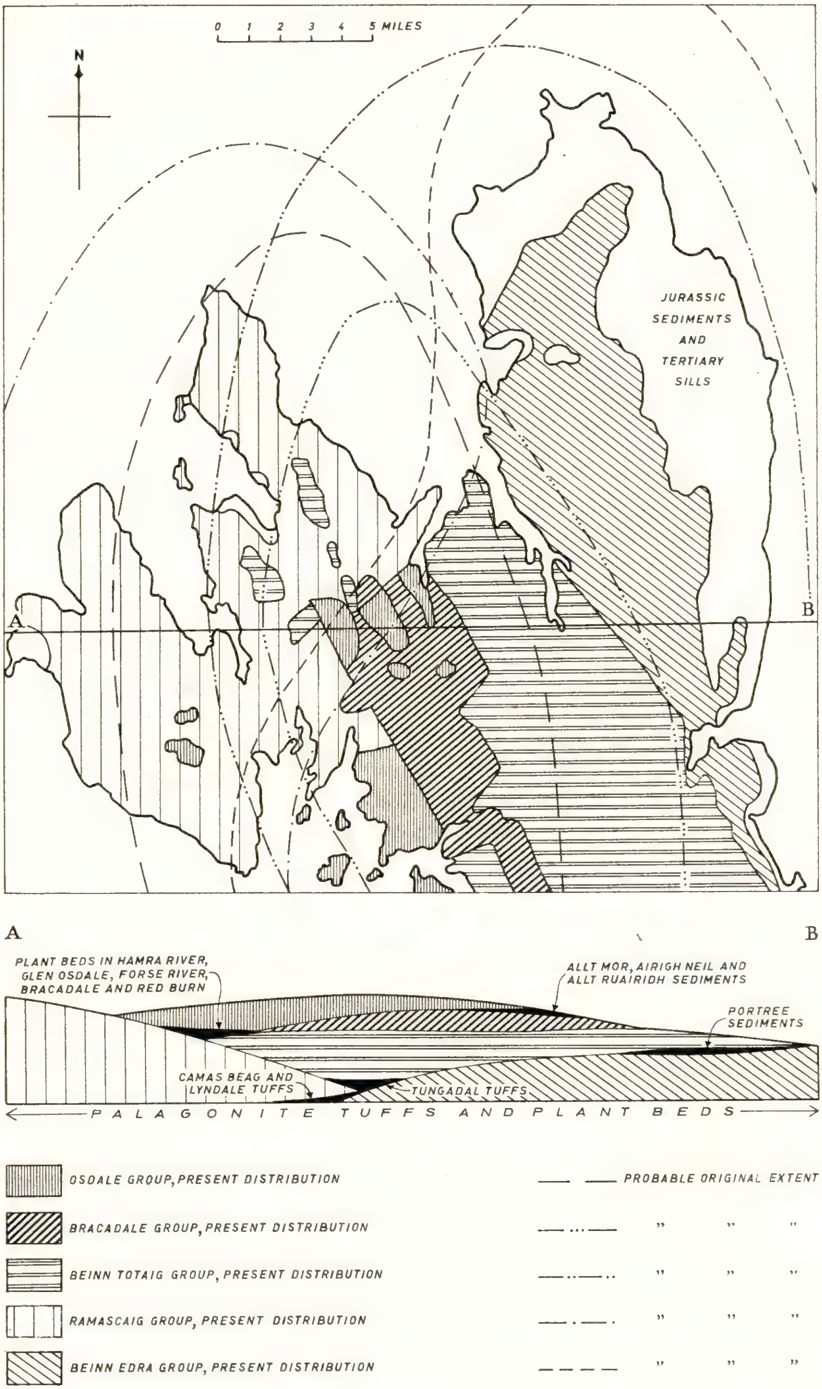

0 1 2 3 4 5 MILES
N
JURASSIC SEDIMENTS AND TERTIARY SILLS
A
B
A
B
PLANT BEDS IN HAMRA RIVER, GLEN OSDALE, FORSE RIVER, BRACADALE AND RED BURN
ALLT MOR, AIRIGH NEIL AND ALLT RUAIRIDH SEDIMENTS
PORTREE SEDIMENTS
CAMAS BEAG AND LYNDALE TUFFS
TUNGADAL TUFFS
PALAGONITE TUFFS AND PLANT BEDS
OSDALE GROUP, PRESENT DISTRIBUTION
BRACADALE GROUP, PRESENT DISTRIBUTION
BEINN TOTAIG GROUP, PRESENT DISTRIBUTION
RAMASCAIG GROUP, PRESENT DISTRIBUTION
BEINN EDRA GROUP, PRESENT DISTRIBUTION
PROBABLE ORIGINAL EXTENT
" " "
" " "
" " "
" " "

FIG. 13. *Sketch-map showing the outcrops of the main lava-groups and section showing their mutual relationships. The suggested former limits of the groups are projected from the known thickness of the present day remnants. Intervals, between extrusive episodes are represented in many places by plant-bearing sediments and tuffs.*

seen from The Storr to Beinn Edra. The mugearitic basalt is a striking feature having all the appearance of a columnar sill when seen from a distance.

The following section was measured in the cliff south of Coire Faoin and continued upwards in the southermost gully on the main east face of The Storr.

Section of lavas at The Storr

(A, Storr gully; B, Coire Faoin cliff)

			ft
A.	24.	Mugearite. grey, platy, forms a small outlier on the summit of the mountian. (37822)[1]	10
	23.	Mugearitic-basalt, fine-grained, platy, olivine-phyric, feldspars have labradorite cores, but are zoned to oligoclase (37921). Lavas show crude columnar jointing, well-developed red bole at top	25
	22.	Basalt, dark, grey, massive, olivine-phyric (37919), capped by well-developed bole in which the basaltic texture is still visible (37920), but containing abundant stilbite, analcime and chabazite	55
	21.	Basalt. Red bole full of amygdales with zeolites	5
		Amygdaloidal basalt	9
		Massive, porphyritic olivine-basalt with olivines up to 3 mm across (37918)	10
		Amygdaloidal basalt with chabazite	11
		Massive olivine-basalt	10
	20.	Olivine-basalt, grey, porphyritic with corroded olivines up to 3 mm across, labradorites 0·2-0·7 mm long, small granular augites, sparse ores (37917). Red top	12
	19.	Olivine-basalt, dark grey, microporphyritic, olivine-phyric with small round amygdales filled with analcite (37916). Red top	10
	18.	Basalt, highly amygdaloidal, altered, soft. Perhaps two thin flows; a thin red parting in centre and a thin red bole on top	12
	17.	Olivine-basalt, massive, rather coarse, with olivine phenocrysts of 0·4-1·0 mm diameter, and groundmass labradorite near 0·5 mm long (37915). Shows flow-banding and a well-defined plane at the top	30
	16.	Olivine-basalt, dark grey, platy, fine-grained with elongate olivines up to 1·0 × 0·25 mm, in labradorite-granular augite groundmass (37914). Close spaced horizontal joints, some lined with zeolites. Reddened top	20
	15.	Olivine-basalt, dark grey, coarse (doleritic), with labradorites up to 3 mm long but averaging 0·5 mm. Small amygdales carrying analcite and chabazite (37913). Six-inch bole on top	30
	14.	Olivine-basalt, massive, doleritic, with labradorites averaging about 0·75 mm long; intergranular augite and abundant thomsonite and chabazite (37912). Thin red bole on top. Base not seen but thought to be nearly same horizon as top of Flow 13	50
B.	13.	Olivine-basalt, highly amygdaloidal, grey, microporphyritic olivine-phyric, in part chloritized. Amygdales with chlorite, chabazite, analcime (37911). Some thin massive layers. A tongue of dolerite is intruded into this flow from an adjacent dyke	at least 60
	12.	Olivine-basalt, smooth-weathering, olivine-phyric, coarse, approaching dolerite (37909). Contains sharply defined layers of amygdaloid, and patches of pegmatitoid with coarse labradorite, augite, zeolites (37910). Red bole at top	at least 80
	11.	Olivine-basalt, massive, coarsely-jointed, microporphyritic olivine-phyric (37908). Pools of zeolites, mostly chabazite. Top fairly well defined but not reddened	20

---

[1] Numbers refer to rock slices in the Geological Survey Collections.

		ft
10.	Porphyritic-basalt, porphyritic feldspar-phyric, with labradorites up to 3 mm long, completely altered olivines and fresh, purplish grey intersertal augites (37907). Amygdaloidal in places. Reddened at top	40
9.	Olivine-basalt, amygdaloidal microporphyritic olivine-phyric, with lenses of compact basalt (37906). Thin red bole at top	45
8.	Olivine-basalt, olivine-phyric, corroded olivines up to 1 mm across. Abundant chabazite in amygdales (37905). Flow impersistent. Reddened at top	0-15
7.	Olivine-basalt, in part highly amygdaloidal but with large irregular lenses of fresh doleritic basalt containing labradorites up to 1·75 mm long, olivines up to 1·5 mm diameter, tiny granules of augite and abundant analcime (37904). Bole at top	40
6.	Olivine-basalt, microporphyritic, olivine-phyric, lower and upper parts very amygdaloidal, centre massive (37903). Red bole at top	35
5.	Olivine-basalt, grey, microporphyritic labradorite-olivine-phyric (37902). Red bole at top up to 2½ ft thick	12
4.	Olivine-basalt, thick, black-weathering, macroporphyritic olivine-phyric (37900), in part heavily zeolitic but with rounded patches of fresh, massive basalt containing pegmatitoid regions in which the labradorites average at least 1 mm long (37901). No sign of an intermediate parting but a 6-in red bole at top	95
3.	Olivine-basalt, massive, irregularly-jointed, microporphyritic olivine-phyric (37899). Red at top	15-20
2.	Olivine-basalt, massive, microporphyritic, ophitic, (37898). A suggestion of columnar jointing. An irregular amygdaloidal basalt occurs in the lower 12 ft, but this is locally cut out by massive basalt. A thin red bole at top	50
1.	Olivine-basalt, grey, microporphyritic labradorite-olivine-phyric (37896). Heavily chloritized in part and zeolitized, chiefly with chabazite (37897). Red bole at top up to 12 in thick. Base concealed by scree	30+

NOTE. It is estimated that a further 400 ft of lava is concealed under scree and landslip.

Further north at the Quirang a section in this same series of lavas was measured from the summit above The Table down the second gully in Maoladh Mor, S.E. of The Table. The sequence here bears direct comparison with that of The Storr approximately ten miles further south.

Section of lavas at the Quirang

		ft
11.	Olivine-basalt, grey, microporphyritic olivine-phyric (37895), containing chabazite-filled amygdales (This is the highest lava seen in the Staffin area and probably lies about 150 ft below the mugearite which caps the ridge south from Beinn Edra).	20
10.	Olivine-basalt, grey, chloritized, olivine-phyric, showing wedge-bedding. Amygdales contain chabazite and 'viridite'; olivine has been replaced by bowlingite (37893-4)	15-20
9.	Olivine-basalt, grey, fairly massive, microporphyritic olivine-phyric (37892). Capped by a well-defined red bole	35
8.	Olivine-basalt, grey, amygdaloidal, microporphyritic olivine-phyric. Amygdales with chabazite and chlorite (37891). Fairly massive as seen in gully	40
7.	Olivine-basalt, dark grey, massive, microporphyritic olivine-phyric, with sub-ophitic augite up to 1·5 mm across, enclosing labradorite laths of 0·2-0·25 mm long (37890) In the gully no persistent parting could be found in this lava, but in the east face of the cliff, a double parting at about the middle could be seen,	120

	ft
so that this may represent at least two flows. A persistent plane marked the top but there was no bole.	
6. Porphyritic basalt, dark grey, microporphyritic, with a few labradorites up to 0·7 mm long (37889). The top is slightly reddened	40
5. Olivine-basalt, grey, massive, olivine-phyric (37888). The top not defined by a bole and not very certain.	
4. Olivine-basalt	
c. Very amygdaloidal olivine-basalt with thin red bole at top.	
b. Dark grey, massive, almost free from amygdales, striped, microporphyritic olivine-phyric basalt (37887) containing 'pegmatitoid' patches with augite, plagioclase, apatite, ilmenite, analcime, chabazite	15
a. Dark grey, highly amygdaloidal, olivine-phyric basalt with chlorite and chabazite in amygdales (37886)	12
(Probably Flow 7 of The Storr sequence where however, the central portion (b) above is in the form of irregular lenses.)	
3. Olivine-basalt, dark greenish-grey, chloritized, amygdaloidal in places, containing sub-ophitic augite up to 0·7 mm across (37885). Red layers at top	20
2. Olivine-basalt, dark grey, altered, highly amygdaloidal especially in a layer 6-10 ft above the base, less amygdaloidal above (37884). Bole at top up to 12 in thick	35
1. Olivine-basalt, dark grey, microporphyritic olivine-phyric (37880-1). Base not seen. Hard ribs up to 2 ft thick, flow-banded, with horizontal 'pegmatitoid' veins carrying clinopyroxene, ilmenite, thomsonite (37882). Top 6 ft highly amygdaloidal, with chabazite. Patchy bole, apparently formed *in situ*, which in places preserves the basaltic texture but elswhere obliterates it (37883)	50

Comparing this section with that at The Storr it will be seen that in general individual flows are slightly thicker at the latter locality. In total there is apparenty a difference of some 350 ft over the same range of flows. No great significance can be attached to this difference except that it may be an indication that the centre of extrusion was located nearer The Storr than the Quirang.

The remanent magnetism of the Trotternish lavas has been investigated by Khan (1960). By comparing the magnetic declination and inclination of individual flows at The Storr and Quirang he has suggested that the lowest exposed flow at the Quirang is the tenth flow up in The Storr sequence. This correlation, however, raises difficulties since the field evidence suggests that the lowest visible flows at the two localities lie at much the same height above the true base of the lava series and Khan's correlation implies what appears to be a rather excessive overlap of more than 700 ft between the two places. The petrology of individual flows is of little help since differences are small but if the secular variation is plotted against true thickness and not as Khan has done (fig. 8, p. 57) simply against a flow number then an alternative correlation is not only possible but is more in accord with the field evidence. In the first place a threefold phase of extrusion is evident, i.e. an early stage during which the individual flows rarely exceed 50 ft in thickness and are usually capped by well developed bole, and which appear to thin northwards, though this is difficult to establish because the lower flows are generally concealed by scree. Probably the lowest 650 ft of The Storr sequence belongs to this stage. The second stage, the climax of the extrusive activity, gave rise to thick flows in quick succession since boles are usually poorly developed or absent. About 200 ft of lava represent this stage—lavas 4 to 9 at The Storr and 4-7 at the Quirang. There is little evidence of any thinning to the north. The final stage consists of flows which at first are of considerable thickness but which later are rarely more than 15 ft in thickness and appear to be dying out rapidly northwards. At The Storr this series of lavas is about 500 ft in thickness apparently reduced to little more than 200 ft at The Quirang.

If Khan's results are re-examined with this argument in mind the correlation would be as follows—first phase, lavas 1-3 in The Storr and Quirang succession; second phase, lavas 4-9 at The Storr and 4-7 at the Quirang; third phase, lavas 10-17 at The Storr and 8-11 at the Quirang. Thus lava-flow 10 at The Storr is equated with flow 8 at the Quirang. The secular variation in these flows is almost identical e.g. declination 177° at The Storr, 173° at the Quirang; inclination 67° in both localities. Declinations also agree well in flows 3-6, i.e. at The Storr 187°, 197°, 204°, 190°; at the Quirang 183°, 198°, 207°, 191°. Inclinations approximate less closely i.e. at The Storr 46°, 67°, 71°, 83°; at the Quirang 47°, 52°, 52°, 57°.

In the lowest flow seen the inclination is the same at both localities but the declination differs considerably (196° at The Storr, 161° at the Quirang) and both declinations and inclinations in Flow 2 differ so considerably that it is probable that Flow 2 at The Storr is not represented in the Quirang sequence at all. Correspondence between the degree of declination could scarcely be closer throughout the sequence and the degree of inclination is the same in lava 10 at The Storr and lava 8 at the Quirang. The lower flows also correspond reasonably well in this respect but flows 4, 5 and 6 show a curious discrepancy in degree of inclination. Flows 7, 8 and 9 at The Storr appear to be the same as Flow 7 of the Quirang sequence for although no bole could be detected in the latter a double parting was seen near the middle.

Southwards from The Storr the mugearite capping the Storr-Beinn Edra escarpment is seen in a downfaulted block at the summit of A'Chorra-bheinn. The mugearite capping the cliff at Sithean Bhealaich Chumhaing is probably the same flow. Here the mugearite cannot be more than 600 ft above the base of the lavas whereas at The Storr this distance must be over 1100 ft.

The mugearite exposed in places south of Tianavaig Bay in the Ollach district may be again the same flow but in this area cannot be more than 100 ft above the base of the lavas.

If these suggested correlations are correct then the Beinn Edra group of lavas shows thinning southwards from The Storr by steady overlap of the higher flows and the southern limit of this group cannot be traced beyond the one-inch sheet boundary.

In the Ollach area a thin porphyritic basalt lies not far above the mugearite. This is regarded as the highest known flow of the Beinn Edra Group. Both these flows should be exposed in Ben Tianavaig but much of the hill is peat-covered and they have not been definitely located. A coarse Hebridean type basalt which forms a more or less continuous feature round the mountain may be that numbered 7 in The Storr sequence. It contains labradorite averaging 0·7 mm long, olivine up to 1·5 mm, ophitic augites up to 3 mm and interstitial analcime and thomsonite. Some distance above it is a microporphyritic labradorite-olivine-phyric basalt which may possibly be Flow 10 of The Storr sequence.

A porphyritic basalt exposed in the stream at Hinnisdal Bridge may be Flow 10 of The Storr sequence and if so is the most westerly recognizable flow at the northern end of this group.

RAMASAIG GROUP

The basalts included in the Ramasaig Group, taking their name from a bay on the west coast of Duirinish, clearly belong to the lower suite of lavas. They differ from those of the Beinn Edra group chiefly in being more frequently porphyritic. They may even have been contemporaneous with that group for though they are described here as if they were later, the two groups have not been seen in contact and there is no field evidence as to their relative ages.

The Ramasaig Group consists of a series of alternating non-porphyritic and porphyritic basalts, the latter distinguishable in the field by their characteristic grey colour. Near the top of the group as seen in Healaval Bheag there is a mugearitic flow. Several basalts of the Hebridean type are found in this group. These lavas appear to have originated somewhere in the Loch Bracadale area or possibly somewhere offshore N.W. of Idrigil Point. They thin to the north and north-east, to the west are faulted down below sea-level and in the east and south are covered by more recent flows. Thinning is evidenced not only by the dying out of the porphyritic basalts to north and east but also by a general thinning of all flows. In the Ben Connan area individual flows appear to average 80 ft in thickness, at Ben Corkeval they average between 60 and 70 ft, at Dunvegan Head about 60 ft and at Ben Geary in Vaternish they are not more than 45 ft in average thickness. Probably all these estimates are too large since it is impossible to be certain of finding the base of every lava in drift- and peat-covered country. The area covered coincides roughly with that in which the gabbroic dykes are found. The base of this group appears above sea-level at Waterstein Head, on both sides of Moonen Bay, at Oans, and at the west of Dunvegan Head, though everywhere the contact with the underlying rocks is covered by scree or landslip or both.

A typical sequence near the centre of the group is that at Ben Connan.

Sequence of lavas, Ben Connan

10. Mugearite, forming the cap to the hill; base of Osdale Group (33801).
9. Olivine-basalt, with platy olivines and ophitic augite (33800).
8. Olivine-poor basalt, intergranular augite, brown and green devitrified glass? (33799).
7. Olivine-basalt, ophitic augite, chabazite (33798).
6. Olivine-basalt, olivine-rich, sparse pyroxenes and ores (33797).
5. Olivine-basalt, platy olivine, zoned plagioclase, ophitic augite, analcime and chabazite (33796).
4. Olivine-basalt, fresh olivines, ophitic augite, analcime, thomsonite and chabazite (33795). Items 4-6 are mapped as one flow.
3. ?Porphyritic basalt, large olivines, intergranular augite, with magnetite and haematite (33794).
2. Olivine-basalt, platy olivines, ophitic augite (33793).
1. Olivine-basalt, fresh olivines, intersertal augite, fibrous zeolite (33792).

The ten (or more) flows have a total thickness of about 800 ft. The sequence of lavas is continued upwards for a further 600 ft in Healaval Bheag.

Sequence of lavas in Healaval Bheag

8. Olivine-basalt, ophitic augite (38094).
7. Basalt, Vaternish Hebridean type, ophitic augite, thomsonite, zeolites (38095).
6. Porphyritic-basalts, platy olivines, feldspar-phyric, colourless intergranular augite; two similar flows (33830).
5. Olivine-basalt, medium-sized olivines, zoned feldspars, ophitic augite (38028)
4. Porphyritic-basalts, feldspar-phyric, olivine-bearing, ophitic augite; two similar flows not separated on six-inch maps (33826-7).
3. Basalt, large olivines, intergranular augite (33825).
2. Olivine-basalt, large olivines, intergranular augite (33821-4).
1. Mugearite. The flow forming the summit rock of Ben Connan (33819).

The Ben Connan and Healaval Bheag sections together represent the upper part of the Ramasaig Group. The lower flows are best seen in the Ramasaig-Ben Corkeval area where at least six porphyritic basalt flows are interleaved amongst the olivine-basalts. At least twelve flows are present in a thickness of about 1000 ft. Thus the total thickness of the group cannot have been less than 2500 ft in the centre.

The lower half of this series of lavas includes two flows of Hebridean type basalts. It is estimated to be 1000-1100 ft thick in the Ben Corkeval area but at Dunvegan Head has apparently thinned to about 800 ft; north-east at Beinn Bhreac it is about 500 ft and at Ben Geary in Vaternish about 300 ft. The upper portion, which includes a mugearitic flow, Hebridean type basalts and porphyritic basalts, is probably 1400-1500 ft thick at maximum but thins to 500-600 ft at Beinn Bhreac, and 300-400 ft at Ben Geary. The reduced sequence of flows at Ben Geary is as follows:

Sequence of lavas at Ben Geary

18. Olivine-basalt, olivine-phyric, micro-porphyritic, intersertal augite, chabazite (31302).
17. Olivine-basalt, as 18, with chabazite, thomsonite and chlorite (31303).
16. Olivine-basalt, microporphyritic, olivine-phyric, ophitic augite, chabazite and analcime (31304).
15. Olivine-basalt, microporphyritic, olivine-phyric, intergranular augite, chabazite, analcime (31305).
14. Olivine-basalt, microporphyritic, olivine-phyric, ophitic augite, zeolites (31306).
13. Olivine-basalt, as 14 (31307). Items 13-16 are mapped as one flow.
12. Basalt, microporphyritic, olivine-phyric, intersertal augite, analcime (31308).
11. Basalt, microporphyritic, olivine-phyric, ophitic augite, chabazite, thomsonite (31309). Items 11 and 12 as one flow.
10. Olivine-basalt, as 11 (31310).
9. Olivine-basalt, as 11 (31311). Items 9 and 10 are mapped as one flow with two other similar flows between 8 and 9.
8. Olivine-basalt, microporphyritic, olivine-phyric, intersertal augite, chabazite, analcime, zeolites (31312).
7. Olivine-basalt, microporphyritic, olivine-phyric, intergranular augite, calcite, zeolites. Shows flow-structure (31313).
6. Olivine-basalt, microporphyritic, olivine-phyric, intergranular augite, chabazite, thomsonite (31314). Items 6 and 7 are mapped as one flow.
5. Porphyritic-basalt, microporphyritic, olivine-feldspar-phyric, intergranular augite, chabazite (31315).
4. Olivine-basalt, microporphyritic, olivine-phyric, intergranular augite, chabazite (31316). A similar flow is also mapped between 3 and 4.
3. Porphyritic-basalt, microporphyritic, olivine-feldspar-phyric, intergranular augite (31317).
2. Olivine-basalt, microporphyritic, olivine-phyric, ophitic augite (31318).
1. Olivine-basalt, microporphyritic, olivine-phyric, ophitic augite (31319). Items 1-3 are mapped as one flow.

BEINN TOTAIG GROUP

The Beinn Totaig Group of lava flows, named from the hill N.E. of Loch Harport, corresponds with the lower third of the Upper Series of Mull. They are basalts, with several thick mugearitic flows and a porphyritic basalt at the top of the group, which appear to have been extruded from a fissure in the Mugeary area, 4 miles S.W. of Portree. The mugearites and basalts occupy a wide arcuate belt from Roineval (just over the southern boundary of one-inch Portree (80) Sheet) to Loch Greshornish including Druim na Criche, Creag a'Chait, Skriaig, Beinn na Greine, Beinn Totaig, Ben Duagrich, Ben Grasco and Ben Uigshader.

A typical section in this group is that measured in the eastern slopes of Beinn na Greine, two miles south-west of Portree:

Section of lavas at Beinn na Greine

12. Olivine-basalt, coarse, with analcime (38011, 38012). The summit cairn at 1367 ft contains large blocks of mugearite but no exposure of this rock could be found at this level.

		ft
11.	Olivine-basalt, micro-porphyritic, labradorite-olivine-phyric (38010). Forms a feature above the head of a stream at about 1150 ft above sea-level. Items 11 and 12 are mapped as one flow.	
10.	Mugearite (38009). A columnar flow with slender columns which forms a feature at about 1100 ft.	40
9.	Mugearite (38008). Columnar.	12+
8.	Mugearite (38007). Platy with a few labradorite phenocrysts. Items 8-10 are mapped as one flow.	30+
7.	Olivine-basalt (38006). Platy weathering. Exposed at about 1000 ft O.D.	25
6.	Olivine-basalt (38004). Massive olivine-phyric, subophitic, cut by a mugearite-basalt dyke (38005).	30+
5.	Olivine-basalt (38003). Dark grey, fine-grained. Olivine much altered to bowlingite. Bole at top.	20
4.	Basalt. An alkaline olivine-basalt forming a strong feature. Layers of pegmatitoid with labradorite, clinopyroxene, ores, thomsonite and analcime near top (38002). Bole at top. Items 4 to 7 are mapped as one flow.	40+
	Gap of approximately 150 ft probably covering basalt and mugearite flows.	
3.	Mugearite (38000). Black. Apparently with bole above.	12+
2.	Olivine-basalt (37999). Olivine-phyric, amygdaloidal in upper part.	20+
1.	Olivine-basalt (37998). Coarse, olivine-phyric. A small sill is injected into this lava. Items 1 and 2 are mapped as one flow.	50+

This flow is about 600-700 ft above the base of the lavas but the rock is scree-covered. It is probable, however, that another mugearite flow is present in the flows below.

The most interesting feature of this group is the development of composite mugearite lava-flows. These were first described by Harker from Druim na Criche (one-inch Portree (80) Sheet), Roineval (one-inch Glenelg (71) Sheet) and Talisker (one-inch Minginish (70) Sheet) as composite double sills or laccolites. Kennedy (1931) has shown however, that the examples quoted by Harker are composite lava-flows. The survey of one-inch Sheet 80 has amply confirmed Kennedy's view and has shown that such flows are common in the central area extending from Roineval in the south to Beinn na Boineide, 13 miles to the north-west. These flows consist of a non-porphyritic portion, usually the lower, and a porphyritic portion. The non-porphyritic rock is a normal platy mugearite carrying plagioclase (labradorite) phenocrysts. At Roineval this kind of relationship is well seen—here over a distance of a few inches the non-porphyritic phase passes into the porphyritic by rapid increase in size and number of phenocrysts. At Druim na Criche, 1½ miles N.E. of Roineval, on the other hand, the two rocks are separated by a sharp boundary. At Talisker there is a gradual transition between the types as at Roineval. Though the field relationships elsewhere are not so clearly seen as at the three localities mentioned it would appear that the porphyritic mugearite can occur as a separate flow and in those cases in which it lies below a non-porphyritic mugearite the two are probably quite distinct flows. In the Dunvegan area the porphyritic-mugearites are extremely well developed with very large labradorite phenocrysts.

These porphyritic mugearites, except in the extreme south of the sheet, only occur in the upper part of the Beinn Totaig Group as at Druim na Criche. It is thought that this group fills the space between the Ramasaig lavas to the west and the Beinn Edra lavas to the east. The top of the group is taken to be the porphyritic basalt flow which forms the cap of Braon a'Mheallain and of Beinn Bhreac, and is exposed in Glen Osdale. At about this horizon there was a pause in the volcanic activity and ashy and shaly sediments with plants were laid down. These plants beds in Glen Osdale have yielded the best preserved Tertiary plant remains known from Skye. A small expanse of sediment one-third of a mile north of Loch Dearg, south-east of Druim na

Criche may be of the same age, as also may the tuffs just west of Gesto House on the north-east side of Loch Harport. The distribution of this group of lavas coincides roughly with the area in which the mugearite dykes and sills are found.

BRACADALE GROUP

After the extrusion of the mugearites and basalts of the Beinn Totaig Group the centre of extrusion appears to have shifted westwards to a fissure lying along the line Ben Scudaig-Ben Aketil. The magma had become more acid by this time and the products of the eruption were primarily mugearite lavas, porphyritic and non-porphyritic with subordinate trachyte and trachytic tuffs. As might be expected the trachytes have a more limited distribution and it is only in the Ben Scudaig area where all four flows are seen. In all directions from this centre the lavas thin and the trachyte flows disappear one by one.

This group is best seen at Ros a'Mheallain north of the large fault which traverses Loch Beag and Allt Mor. The summit of the hill is a big-feldspar mugearite similar to those at Roineval. The base of this flow is scree covered and the next rock exposed below is a slaggy trachyte seen in the slope above the feature made by a mugearite, below which again, at road level is another trachyte with abundant stilbite.

A more extended, but not so clearly exposed sequence is to be found on the south-western slope of Ben Scudaig. Here is the most complete succession of the group, consisting of porphyritic and non-porphyritic mugearites with four trachyte horizons, of which one at least is a double flow with a bole between. The group here is about 400 ft thick.

The most southerly trachytes in one-inch Portree (80) Sheet are those exposed in the Sumardale River and its tributaries south of Beinn nan Lochan. The Druim na Criche ridge is formed by the attenuated eastern extension of the group. To the north the trachytes are seen in Glen Colbost and in the valleys of Abhainn Bhaile Mheadonaich and Allt Ruairidh. The area two to three miles south of Edinbain contains many small exposures of the trachyte flows and some of the finest examples of the big-feldspar mugearites. A small outcrop of trachyte just north-east of Strone Geers and the mugearites of Beinn na Boineide, Upperglen and Beinn Eirisalain comprise the most northerly examples of the group now remaining. The Bracadale Group is the most restricted both in extent and thickness of all the lava groups. On the general principle that the basic lavas are more fluid than the acid this is only to be expected. Nor is it surprising to find that the acid dykes and sills have a distribution similar to that of the more acid lavas.

OSDALE GROUP

The mugearites and trachytes of the Bracadale Group are succeeded by a sequence of basalts and mugearites similar to that of the Beinn Totaig group. Only remnants of this, the latest series of lavas, have survived, but their distribution suggests that they were derived from a fissure still further to the west. The islands of Wiay, Harlosh, and Oronsay, the northern end of the Minginish promontory, the area round Struan and Struanmore, Boust Hill, Colbost and Osdale in the south and in the north Cruachan Beinn a'Chearcaill and Ben Aketil are composed of lavas of this group. Porphyritic mugearites are present but their relationship to the non-porphyritic mugearite is nowhere very clear.

This area of distribution is, coincidently, or not, that in which the tholeiite dykes found.

MAGMATIC SOURCES FOR THE LAVA SUITE

The sequence and distribution of lavas in North Skye suggests that though closely linked to the site of the Central Volcano in the Cuillin area, the lavas were actually extruded from local reservoirs developed as shallow offshoots from the main magma mass and subsequently becoming independent of it. During the period in which the lavas were being extruded the main magma was becoming more acid and the local reservoirs represented samples taken from the magma at successive stages in this process, probably because of their geographical relationships to the main magma reservoir. The first stage was the formation of a tuff vent somewhere in the Portree area. Palagonite tuffs are found wherever the base of the lavas is exposed but in the Portree area they are much thicker than elsewhere. At this stage the Cuillin Volcano may have become established as a tuff cone with only subordinate lavas of limited extent. Later a vent opened in a fissure further north and basalt lavas were extruded, slowly at first since the thick boles of the lowest lavas indicate long pauses between flows. Eventually a lava plateau of 1000 ft was built up extending over half the island. Meanwhile a second vent had opened in the west. Again the initial stages were slow and sediments were able to accumulate in places between flows. Lavas, porphyritic and non-porphyritic basalts (of the Hebridean type) eventually built up until the western half of the island was covered to a depth of 2000 ft. In both the early vents the magma pressure must have dropped towards the end of the phase and mugearites were drawn off.

A third stage was the opening of a vent west of the first towards the centre of the northern part of the island from which were extruded mugearites and basalts. In this case the main magma reservoir must have been tapped near the basalt-mugearite junction so that repeated pulses in magma pressure produced first basalt flows then mugearite flows. The next eruption took place from a vent still further westwards and one which tapped the main reservoir at a higher level, i.e. at about the trachyte-mugearite junction so that in this case the alteration of lavas was trachyte-mugearite. A further westward migration tapped the reservoir at much the same level as at the fourth stage and again the flows were alternating basalts and mugearites. The final phase in the expanding magma period was the intrusion of a large dolerite sill in the underlying Jurassic sediments. The sill underlies the whole area and in bulk of magma must have represented little less than one quarter of that extruded as lava. It maintained a close approximation to a single isobaric level which is much the same as that occupied by the main gabbro laccolite of the Cuillins.

The final stage in the volcanic history of North Skye was the collapse of the area overlying the main magma reservoir, *pari passu* with the intrusion of a great swarm of dykes. That the two phenomena were penecontemporaneous is shown by the fact that many dykes occupy fault planes whilst many others cut across them.

From the nature and direction of the fractures it is inferred that the main magma reservoir had the form of an inverted V-shaped cleft trending N.N.W. more or less along the line marked by the eastern coast of Vaternish.

Though the majority of the dykes are dolerites and definitely associated with the Cuillin centre, and the increase in density and size of the dolerite dykes as the gabbro mass is approached is very striking, there are others which are geographically related to the lavas. The area within which the picrite dykes are found is that covered by the lavas of the Beinn Edra Group. The gabbroic dykes are found in the Ramascaig Group area, the mugearite dykes in the Beinn Totaig Group area, the trachyte dykes in the Bracadale Group area and the tholeiite dykes, which are as usual late, are found in the Osdale Group area. Thus there appears to be an association of dykes and lavas which can hardly be coincidental:

Beinn Edra Group Lavas—Olivine-basalts—picrite dykes
Ramascaig Group Lavas—Porphyritic and non-porphyritic basalts—gabbroic dykes
Beinn Totaig Group Lavas—Mugearites and basalts—mugearite dykes
Bracadale Group Lavas—Trachytes and mugearites—trachyte dykes
Osdale Group Lavas—Mugearites and basalts—tholeiite dykes

The only possible explanation of this association is that beneath each lava field was established an intermediate reservoir fed from the main magma and of the same composition as the lavas above. In fact the lavas were extruded through fissures from the intermediate reservoir and not directly from the main magma. It is probable that crystallization began in these intermediate reservoirs rather than in the main magma, in which case the extrusion of coarsely porphyritic lavas of remarkably uniform composition and of composite flows is readily understood, for these intermediate reservoirs were probably sill-like bodies in which layering could easily take place. The collapse of the roof of the main magma which eventually took place must have squeezed out the magma remaining in the intermediate reservoirs, through innumerable fissures, in the form of dykes. It is not possible to substantiate Harker's postulate that the dykes were feeders either for the lavas or for the sills. No case of such a relationship has been established and all the dykes appear to be later than all the lavas. It is more likely that the feeders were few and large like those now operating in the lava-field of Hekla in Iceland.

References

Brown, P. E. and Miller, J. A. 1963. On Dating the British Tertiary Igneous Province. *Geol. Mag.*, **100**, 381-3.

Gardner, J. S. 1887. On the Leaf-beds and Gravels of Ardtun, Carsaig, etc., in Mull. *Quart. J. Geol. Soc.*, **43**, 270-300.

Harker, A. 1904. The Tertiary Igneous Rocks of Skye. *Mem. Geol. Surv.*

Kennedy, W. Q. 1931. On Composite Lava Flows. *Geol. Mag.*, **68**, 166-81.

Khan, M. A. 1960. The remanent magnetization of the basic Tertiary igneous rocks of Skye, Inverness-shire. *Geophys. Roy. Astronom. Soc.*, **3**, 45-62.

Macculloch, J. 1819. *A Description of the Western Islands of Scotland.* London.

Manum, S. 1962. Studies in the Tertiary flora of Spitsbergen. *Norsk. Polarinstitutt Skr. Nr.*, **125**, 1-127.

Pflug, H. D. 1956. Sporen und pollen von Tröllatiia (Island) und ihre Stellung zu den pollenstratigraphischen Bildern Mitteleuropas. *Neues Jb. Geol. Abh.*, **102**, 409-30.

Simpson, J. B. 1951. The age of Tertiary vulcanicity in Scotland. *British Assoc. for Adv. Sci.*, Edinburgh, p. 63.

—— 1952. *in* Eyles, V. A., The composition and origin of the Antrim laterites and bauxites. *Mem. Geol. Surv.*

—— 1961. The Tertiary Pollen-Flora of Mull and Ardnamurchan. *Trans. Roy. Soc. Edin.*, **64**, 421-68.

Watts, W. A. 1962. Early Tertiary Pollen Deposits in Ireland. *Nature*, **193**, **600**.

Chapter VII

PETROGRAPHY OF THE VOLCANIC ROCKS

History of Research

The earliest investigator of the lava-field of Skye, John Macculloch (1816, 1817, 1819) had none of the benefits of microscopical petrography, and it was not until the time of Zirkel in 1870 that modern techniques were first applied to the basalts. Meanwhile Archibald Geikie, early in his career, had interested himself in the time-relations of the Scottish trap-rocks (1861, 1867). In 1883 J. W. Judd entered the field with descriptions of a number of occurrences of basaltic glass, in collaboration with G. A. J. Cole. This was followed by a series of papers from Judd, mainly concerned with the broader aspects of the history of the Tertiary volcanoes, and suggesting that the basalt plateaux were formed of lavas emitted at central vents. In 1886 he suggested that the term basalt should be applied only to such rocks as contain some remains of a vitreous groundmass, and that dolerite should be used for holocrystalline basic rocks 'in which the felspar appears in section as an entangled mass of lath-shaped crystals, while the augite and olivine occur either in definite crystals or rounded grains'.

In 1886 Sir Archibald Geikie strongly contested Judd's views on central eruption and advocated quiet emission of the plateau lavas from fissures, a conception which he further developed in his 'Ancient Volcanoes' (1897). This work contains petrographical descriptions of the plateau lavas (Vol. II, pp. 183-4) contributed by F. H. Hatch, W. W. Watts and A. Harker. Geikie recognized five types of lava on the basis of field occurrence: (1) Thick massive prismatic or rudely jointed sheets, including true superficial layers which show the characteristic slaggy or vesicular bands at their upper or lower surfaces; (2) Prismatic or columnar sheets of which he remarks: 'It is not always possible to be certain that columnar sheets which appear to be regularly intercalated among the undoubted lavas . . . may not be really intrusive'; (3) Slaggy or amygdaloidal lavas without any regular jointed structure; (4) Banded or stratiform lavas, owing their layering to regular textural changes, or to bands of vesicles; (5) Lavas showing flow structure, generally of rare occurrence. The first description of the tuff and agglomerate of Portree Harbour was given by Geikie (1897, pp. 284-6) and he also noted the red partings between some of the lavas (p. 254). His main conclusion (p. 255) was that the plateau lavas show no thickening towards a centre.

The primary survey of one-inch sheets 70 and 71 by Alfred Harker formed the basis of his great memoir, published in 1904. The southern part of the lava field, together with a number of relics involved in the Cuillins centres, comes into these sheets, and Harker has remained the main authority on the petrography of the Skye lavas. Like Geikie, he was impressed by the contrast between the unjointed amygdaloidal layers, and the columnar sheets, and rightly remarked (Harker 1904, p. 29) that the latter 'form all the salient features of the plateau country'. Unlike Geikie, however, he confidently reached the conclusion that the prismatic-jointed layers were all dolerite sills, of later date than the lavas. This, as already noted (p. 80), has not been supported by later authors, and Harker's description of the petrography and chemistry of the basalts (pp. 29-50), thus requires to be read in conjunction with his account of the 'Great Group' of basic sills (pp. 235-253). Harker coined the name mugearite for the trachybasaltic sheets of Druim na Criche and Roineval which he regarded as portions of composite sills, the upper member of which was misleadingly described as olivine-dolerite crowded with large porphyritic feldspars. Kennedy (1931) has subsequently brought forward evidence to show that these are composite lava-flows. These bodies lie near the southern margin of the area of one-inch Sheet 80, with which we are here concerned.

G. V. Wilson's reports on the primary survey of one-inch sheets 80 and 90 (Wilson 1935, p. 70; 1936, p. 83; 1937, p. 78) leave no doubt as to the opinion of the surveyors on the question of the extrusive nature of the hard, prismatic layers. The flows are stated to be 'characterized by highly decomposed and slaggy tops and bottoms, with hard black central portions. Occasional thin interbedded layers of red bole, shale and coaly matter also occur, but as yet no intrusive sills have been noted within the lava sequence', (Wilson 1935, p. 70). The primary survey also indicated the extent of the tuff first noted by Geikie, and this is described as a palagonite tuff, containing bombs which consist mainly of devitrified glass with numerous crystals of olivine and feldspar, while in the case of the smaller fragments the matrix is still clear, yellow glass (Wilson 1937, p. 78). The tuff which lies between the Jurassic sedimentary rocks and the basal lava of the Tertiary volcanic suite, is interpreted as indicating that volcanic activity commenced with an explosive phase which ejected a great quantity of glassy materials. Trachytes were first noted from the northern part of the island in 1935 associated with mugearites and big-feldspar basalts.

A general description of the lava plateaux with some support for Judd's conception, has been given by Richey (1948, p. 37 *et. seq.*), and the olivine-basalts, mugearites, feldspar-phyric mugearitic basalts and trachytes have been mentioned in an excursion guide (Wager and others, 1948, p. 8). New analyses of Skye mugearites and trachyte have been included in a petrological study by I. D. Muir and C. E. Tilley (1961) and of basalt in a paper by Tilley and Muir (1962). The magnetic properties of the lavas (p. 85) have been determined by M. A. Khan (1960). Before concluding this review mention must also be made of the many contributions to the mineralogy of Skye by M. F. Heddle, brought together by Goodchild in a posthumous memoir (1901) which includes analyses of most of the zeolites for which The Storr and other localities are famous, as well as of other species. Interest in these minerals has recently been revived by J. M. Sweet (1959, 1960, 1961).

It is also important to recall that petrographical investigation in other Tertiary centres, especially in Mull (Bailey and others, 1924), in Ardnamurchan (Richey and Thomas, 1930) and in Antrim (Tomkeieff 1940, Patterson 1955 A, B) has thrown much light on the petrography and chemistry of the lavas which compose the Tertiary plateaux. The petrological discussions which have accompanied and followed these publications will be referred to in a later chapter.

Palagonite Tuffs

Field Relations. The tuff is associated with carbonaceous sediments of Tertiary age, and underlies the base of the lava sequence. It has been found on the east coast at Camastianavaig, at Camas Ban (Harker 1904, p. 23 figured a section from this locality), and at Red Cliff on the north side of Portree Harbour, whence it is seen at intervals in the cliff section for over 5 miles. About half a mile north of Prince Charles's Cave the outcrop swings inland and the bed forms a capping to the cliffs over a considerable area. It is present at Lon Coire na h-Airidh and farther north has been found on the coast between Staffin and Flodigarry. In Vaternish it has been noted in the vicinity of Halistra and Stein, and along the foot of the Sgurr a'Bhagh landslip on the shore of Loch Bay (Wilson 1937, p. 78).

The deposit, which is visibly fragmental, weathers brown and contains rounded bombs of glassy lava, as well as scattered crystals of olivine and feldspar. It has been found to contain fragments of fossil wood on the coast between Ard Beag and Bay (Wilson 1936, p. 82). At many places, lenticular cakes of lava with pipe amygdales occur in it; there are also lenticular dolerite bodies, some of which are probably intrusive. The suggestion has been made (Wilson 1937, p. 78) that the deposit was laid down in water.

Petrography. The tuff from the excellent exposures at Creag Mor, west of Beal Point (37871[1]) is a dark brown crystal-vitric variety containing conspicuous amygdales or pockets filled with hard white opaline silica. The constituents include crystals of labradorite of approximate composition An_{70}, and beautiful automorphic olivines, some complete, some in fractured condition, with a composition, ascertained by refractive index measurements, corresponding to the range Fa_{16}–Fa_{19}. These are set in a matrix of glass fragments, which display a zonal arrangement within individual fragments. The inner zone is clear yellow glass with refractive index ranging up to 1·595. Having regard to the refractive index measurements of natural basaltic glasses recorded by Tilley (1922), which show a range from 1·586 to 1·649 (excluding glasses with mugearitic affinities), there is little reason to doubt that this is a true basaltic glass or sideromelane. An analysis of the yellow glass is given below (p. 97). The yellow inner zone is separated from the next zone by a region, up to 0·1 mm wide, full of dusty opaque particles. Then follows a narrow green zone, succeeded by clear brown isotropic glass in which the range of refractive index is from 1·545 down to 1·480. This has a fringe showing partial devitrification to 'palagonite'. The zones may enclose olivine or feldspar crystals at any point, and do not in any way conform to the positions of the crystals. Gas cavities occur only in the outer brown zone. Between the glass fragments, white-reflecting isotropic silica with refractive index in the range 1·520-1·525 occurs, probably opal mixed with a little chalcedony. An essentially similar specimen (31751) was obtained from the path side, ¼ mile E.S.E. of Torvaig; here the olivines range up to 2·5 mm across, while the labradorites are no more than 0·6 mm long. Some of the olivines are automorphic, but others have a remarkably corroded appearance in thin section. It is of this specimen that G. V. Wilson (1937, p. 78) remarked 'On closer examination the clear yellow glass is seen to pass outwards through a deep greenish layer into an olive-green layer and finally into an angular, fragmental material in which the interstices are often filled with analcite and opal. It is stated that the appearance of the junction of the glassy and fragmentary types leaves no doubt that the latter was formed *in situ* from the former'. The presence of devitrified fringes round the fragments is again a conspicuous feature. In material from the cliffs 600 yds N. of Rudha na h'Airde Glaise (37967) labradorite laths up to 1·25 mm long and small clinopyroxenes are set in quite isotropic pale yellowish-green fragments with refractive index 1·584-1·596, having devitrified margins; the glass turns dark brown, and is of markedly lower refringence, as the margins are approached. In this rock carbonate with ω = 1·681 (slightly ferriferous dolomite) occurs between the fragments.

---

[1] Five figure numbers in brackets refer to the Scottish Sliced Rock Collection of the Geological Survey and Museum unless otherwise stated. Numbers prefixed by 'Durham' relate to specimens in the collection of the Department of Geology of Durham University.

At Craig Ulatota, the upper 15 ft of the Tertiary sandstone can be seen. This is a pale brown rock (37956) containing angular quartz and alkali-feldspar grains of about 0·15 mm, with a sprinkling of grains of partly oxidized chloritic material perhaps heralding the onset of explosive volcanism. Some 82 ft above the base of the tuff, which here encloses impersistent flows of microporphyritic olivine-basalt (31938) and hyalopilitic basalt containing olivines up to 3·0 mm diameter and Y-terminated labradorites, there occurs a bed of grey and red ashy tuff (37959, 37961) in which glass shards are conspicuous under the microscope. Plant remains occur in this bed, and adventitious quartz-grains, well rounded, are also seen.

From a stream section near Gesto House (31385) comes a vitric tuff containing isotropic brown glass lapilli in a dark, streaky glass matrix.

The tuff exposed at Camas Ban resembles that of Creag Mor except that devitrification has proceeded further, and the matrix contains dolomite and chabazite, but no opal (37923). A volcanic bomb from this locality (37924) proves to be a porphyritic tholeiite containing glomeroporphyritic labradorite, in a groundmass of small labradorites and granular purple augites set in glass carrying plates or rods of iron-titanum oxides. Devitrification of the glass had produced a green mineraloid resembling the 'palagonite' of the tuff.

Chemical Composition of the Sideromelane and Palagonite. The yellow glass with refractive index 1·595 was separated from the Creag Mor rock (37871) by Miss H. A. H. Macdonald and analysed with the result given in Table I, analysis I. The X-ray photograph of the concentrate (X2012) showed only a little impurity, probably feldspar. The norm calculated from the analysis (Table II, p. 99) indicates a composition approaching oversaturated basalt.

The product of devitrification of the sideromelane contains a fibrous mineral in which the fibres display moderate birefringence, up to 0·015, negative elongation and variable refractive index, in the range 1·51 to 1·54. In transmitted light this material is pale to deep brown. Separations were made from a specimen from Camas Ban (40387; Durham 2495) showing, in thin section, glass lapilli preserved in fibrous and radiating 'palagonite'. Gravity methods produced a concentrate containing 89 per cent grains of brown glass in various stages of devitrification; and 11 per cent colourless isotropic grains. Brown and colourless fractions were separated magnetically. The refractive index of the brown fraction was found by Dr. Sabine to lie in the range 1·516-1·531; while the colourless grains show 1·476 and below. Both fractions were analysed (Table I, columns II, III).

The most noteworthy feature is the high Na_2O figure in both analyses II and III; the increase in total alkalis as compared with basaltic glass (column A) is threefold.

TABLE I

Analyses of Palagonite, Glass and Tuff

	I	II	III	A	IV
SiO_2	51·5	56·0$^+$	43·3$^+$	37·8	33·24
Al_2O_3	15·6	15·8	11·5	13·7	21·53
Total Fe as Fe_2O_3	10·6	1·5	14·7	12·3	3·23
MgO	5·7	1·0	2·1	1·9	0·72
CaO	10·4	2·2	1·6	1·6	2·36
Na_2O	3·2	6·2	8·2	3·8	0·13
K_2O	0·6	2·2	0·8	3·4	0·07
Ignition loss	0·7	14·3	16·4	23·0	35·69
TiO_2	1·7	0·8	1·4	—	2·73
P_2O_5	—	—	—	—	0·25
MnO	tr.	tr.	tr.	2·5	0·09
Cl	—	—	—	—	tr.
S	—	—	—	—	Nil.
Cr_2O_3	—	—	—	—	tr.
BaO	—	—	—	—	0·10
Li_2O	—	—	—	—	tr.
	100·0	100·0	100·0	100·0	100·14

	I	II	III	A	IV
FeO	8·9	tr.	1·4	—	—
H_2O below 105°	0·3	5·0	7·3	—	24·65
CO_2	—	—	—	—	0·22
C	—	—	—	—	0·60

$^+$ by difference

I Yellow glass separated from 'palagonite' tuff, n= 1·595, Creag Mor, Skye

II Colourless glass from 'palagonite' tuff, n = 1·476 Camas Ban

III Brown partly devitrified glass from 'palagonite' tuff, Camas Ban

A Palagonite, 2,350 fathoms Pacific Ocean, lat. 13° 28′ S. long. 149° 30′ W. (Peacock, 1930).

IV Interbasaltic deposit, 10 in thick, in Tertiary lavas, Stream 1500 yd S.E. of Blackhill (Edinbain), Skye.

Analysts: I-III, A. D. Wilson (semi-micro methods), Geological Survey and Museum, Lab. Nos. 1740 (1958), 1712, 1713 (1956); A. Sipöcz, recalculated by Peacock; IV, G. A. Sergeant, Geological Survey and Museum, Lab. No. 1086 (1943); Guppy and Sabine 1956, p. 28.

The proper use of von Walterstansen's term 'palagonite' was discussed and clarified in a series of papers by M. A. Peacock (1926, 1928, 1930), who advocated the restriction of the term to the gel-like or obscurely fibrous products of the hydration of sideromelane at low or moderate temperatures. He added 'It occurs typically in dominantly vitreous basaltic tuffs formed under conditions of drastic cooling and subsequent prolonged saturation with water or water vapour' (1930 p. 177). So far the term may aptly be applied to the present material. However, Peacock claimed that palagonite has substantially the composition of basalt to which 20 or 30 per cent water has been added. This is clearly not so in the present case, where there are losses in MgO and CaO, and great gains in Na_2O. The palagonite of Skye is most closely comparable with the skin of sideromelane fragments dredged by the 'Challenger' expedition from the Pacific (Peacock 1930, p. 175; Table I, Column A) which is believed to have acquired alkalis from the sea-water.

It appears, therefore, that the change from sideromelane to palagonite, illustrated in the Skye basalt tuff, is accompanied by hydration, loss of lime and magnesia, and substantial gain of soda. Apparently the process may proceed to a stage where iron also is lost. Whether these changes are due to the eruption of glass fragments into sea-water or whether they also demand the intervention of hot circulating fluids, is less clear.

A thin layer of tuff collected by D. A. Haldane from a horizon between lavas near Edinbain (33954-5) shows another variety of palagonite. The rock is made up of subspheroidal bodies of 0·02-0·25 mm diameter, probably the remains of glass lapilli, set with angular plagioclase crystals in a streaky matrix of dark brown and reddish brown glass. There has been extensive divitrification, indicated by optical activity suggesting an incipient fibrous structure. An analysis (Table I, column IV) shows that in this case, there has been loss of Na_2O, as well as of MgO and CaO as compared with average plateau basalt. In these respects the rock is comparable with the palagonite tuff of Iceland (Peacock, 1926, p. 66) rather than that of Portree. The high alumina, however, suggests that contemporaneous subaerial weathering may also have had some influence on this rock, as in the case of the interbasaltic horizons in Antrim (Eyles 1952).

THOLEIITIC PILLOW LAVAS

Field Relations. At Creag Mor, west of Beal Point, the upper part of the 'Palagonite' tuff, totalling about 60 ft, is seen. About half-way up the section, ashy shales, overlain by 4 ft of yellowish-brown, bedded tuff, is succeeded by lavas having well-developed pillow structure. The surfaces of the pillows are ropy and pipe amygdales occur in the pillows. What appears to be a second horizon of pillow lavas overlies yellow tuff some 12 ft higher in the section.

Petrography and Chemistry. The unaltered sideromelane glass in the palagonite tuff makes it possible to obtain some detailed information of the nature of the earliest magma of the North Skye volcano. Investigation of the pillow lavas, which were undoubtedly contemporaneous with the early explosive phase, also suggests that magma of a type more saturated with silica than that responsible for the great pile of plateau lavas was available at an early stage.

The rock of the pillow lava (37872, 38092) is a micro-porphyritic tholeiitic basalt. The phenocrysts, up to 1 mm long are of fresh clear plagioclase of composition An_{65}; these tend to occur in groups in which the crystals are

TABLE II

Analyses and Norms of Sideromelane, Pillow Lava and Tholeiitic Basalts

Analysis	I		V		VA		B		C	
SiO_2	52·0		42·30		47·6		47·35		49·76	
Al_2O_3	15·6		14·24		15·8		13·90		14·42	
Fe_2O_3	0·7		3·87		4·3		5·87		3·95	
FeO	8·9		5·49		6·2		8·96		7·77	
MgO	5·7		4·42		5·0		5·97		5·30	
CaO	10·4		16·76		12·5		10·65		10·22	
Na_2O	3·2		2·40		2·7		2·73		2·49	
K_2O	0·6		0·27		0·3		0·54		1·83	
H_2O+	0·9		1·22		1·3		1·16		1·03	
H_2O-	0·3		1·69		1·9		1·04		2·04	
TiO_2	1·7		1·57		1·8		1·75		0·94	
P_2O_5	—		0·18		0·2		0·24		0·21	
CO_2	—		5·07		—		0·32		0·06	
S	—		0·09		—		0·23		—	
FeS_2	—		—		—		—		0·04	
Cr_2O_3	—		0·04		—		—		—	
BaO	—		0·07		—		—		0·04	
MnO	tr.		0·24		0·3		0·23		0·20	
	100·0		99·92		99·9		100·94		100·30	
Norm										
Q	—		1·92		2·1		1·08		0·48	
or	3·3		1·67		1·9		2·78		10·56	
ab	27·3		20·44		23·1		23·06		20·96	
an	26·4		26·97		30·5		24·19		22·80	
di- wo	10·6	20·9	9·74	18·72	11·2	21·4	10·67	20·73	11·14	21·86
di- en	5·4		6·60		7·5		6·50		6·10	
di- fs	4·9		2·38		2·7		3·56		4·62	
hy- en	8·8	17·0	4·50	6·35	5·1	7·2	8·40	13·02	7·20	12·48
hy- of	8·2		1·85		2·1		4·62		5·28	
mt	0·9		5·57		6·3		8·58		5·80	
il	3·2		3·04		3·4		3·34		1·67	
ap	—		0·34		0·4		0·34		0·34	
ca	—		11·50		—		0·70		0·10	
py	—		0·30		0·3		0·73		—	
rest	1·2		3·02		3·4		2·20		3·15	
Feldspar	$Or_6Ab_{48}An_{46}$		$Or_3Ab_{42}An_{55}$				$Or_6Ab_{46}An_{48}$		$Or_{19}Ab_{39}An_{42}$	

I Sideromelane from 'Palagonite' Tuff, Camas Ban, Skye
V Pillow lava, Creag Mor, Skye
VA —do—, analysis recalculated free of calcite
B Type Salen tholeiite
C Type Staffa basalt

Analysts: I. A. D. Wilson, Geological Survey Lab. No. 1740 (1958)
V. A. D. Wilson and P. Coombs, Lab. No. 1645 (1954) Guppy and Sabine 1956, p. 28
B. F. R. Ennos, Lab. No. 407 } Bailey and others
C. E. G. Radley, Lab. No. 669 } 1924, p. 17.

separated by black glass. The groundmass consists of plagioclase laths of about 0·1 mm long, not fluxionally arranged, with elongate and dendritic, faintly purple clinopyroxene between them; many of these are obviously incompletely crystallized. Rounded areas of a brown mineraloid may represent former olivines, but this is uncertain. Very dark glass is abundant between the ribs of the dendritic pyroxenes and elsewhere. Rims of the glass, enclosing tiny acicular pyroxenes, surround amygdales which have been filled with carbonate having $\omega = 1{\cdot}662$ (ankeritic calcite) and with chlorite.

An analysis of this rock is given in Table II, column V; in column VA the analysis is recalculated free of calcite, but neglecting the very small quantities of ferrous iron and magnesium in the ankeritic calcite. The results suggests an affinity with the non-porphyritic Central type of basalt, as developed in Mull (Bailey and others 1924, pp. 14, 17) or the Causeway type of Tomkeieff (1940, 1948) than with the Plateau Basalts. The absence of olivine from the norm is, for example, noteworthy. At the same time, it is not desired to lay great stress on this occurrence, having regard to its insignificant proportions compared with the main lava series, and the altered state of the rock.

MAIN LAVA SERIES

Lava types. A total of 396 thin sections of lavas from the main lava series of Northern Skye have been examined in connexion with the present investigation[1]. Six lava types are recognized for descriptive purposes, and in the table below these are briefly defined, with the appropriate symbols. The number of slices in each category is shown and in view of the fact that many serial collections of lava-successions were made during the field survey, and during a visit in 1950, these give a rough impression of the relative abundance of the different types, but probably erring on the low side in the case of the Hebridean type (1).

The Hebridean lava type of Table III corresponds with the 'Plateau Type of Basalt' of the Mull Memoir (Bailey and others 1924, p. 136). The Mull term has not been used here, to avoid confusion with the 'Plateau magma-type' of Bailey and others (1924, p. 14) which involves concepts going far beyond the definition of lavas, and because it is linked to a style of vulcanism not necessarily justified by the evidence in North Skye (p. 160) Tomkeieff's (1948) more non-committal term is thus adopted, but (without prefix) it is restricted here to the finer-grained rocks which fall within the textural category of basalt. Coarser lavas, of similar composition, where the feldspars average over 0·5 mm in length, which would be dolerites on the basis of their textures, have been assigned to the new Vaternish Hebridean type. All the types listed in Table III are recognizable in the field.

---

[1] A preliminary naming of those cut in London (approximately half of the total number) was carried out by Dr. J. Phemister. Part of the remainder were examined by Mr. E. H. Francis in 1950, but the whole series was reinvestigated to provide symbols for the maps and for the present account.

Field Structure. The complete lithological sequence within a single lava-flow of any of the types listed above, appears from the field evidence to be as follows:

4. *Bole* or fossil soil, produced by weathering of the exposed surface of the flow; generally red owing to ferric oxide concentration.
3. *Upper amygdaloidal layer*, representing the upper crust or carapace of the flow in which crystallization commenced during the movement of the flow. May be brecciated; and is generally rich in ovoid gas cavities now filled with zeolites, chlorite, carbonates or, in the case of trachyte flows, agate. The rock is generally of a chilled type, and has often been altered as a result of the passage of fluids (especially water vapour) from the still-liquid magma, and possibly from atmospheric sources, through it.
2. *Central massive layer*, which may or may not exhibit vertical prismatic jointing. Generally made of lava reasonably free from secondary hydrous minerals, this layer was formed when the central layer of magma came to rest and crystallized. Usually contains few gas cavities.
1. *Lower amygdaloidal layer*, composed of chilled lava which encloses many gas cavities, including pipe amygdales which, from their inclination, may have formed when the central magma layer was still moving. The lava here tends to contain more hydroxyl-bearing minerals than the central massive layer. Usually very much thinner than the upper amygdaloidal layer.

The complete four-fold arrangement is not shown by every lava-flow. Some have only poorly-developed central layers, while in other cases the upper and lower carapaces can hardly be distinguished from the massive or prismatic centre. The bole is not invariably present, indicating that at some times during the vulcanicity, flows followed one another in sufficiently rapid succession to

TABLE III

Lava Types in Northern Skye	*Symbol One-inch map*	*Slices*
1. *Hebridean Type of olivine-phyric olivine-basalt*, with ophitic or intergranular augite which may be yellow, pale brown, purple, faintly green or colourless in thin section. Composition of the feldspar in the range An_{55} to An_{70}. Mesostasis of zeolites, especially analcime, thomsonite, chabazite, generally present. Feldspars not exceeding 0·5 mm average length.	B^{He}	214
2. *Vaternish Hebridean Type olivine-phyric olivine-dolerite*, composition similar to Hebridean type but plagioclases average over 0·5 mm long.	B^{V}	42
3. *Feldspar-phyric olivine-basalt*, olivine and labradorite phenocrysts generally of microporphyritic dimensions, (i.e. less than 2 mm), in a groundmass of composition similar to the Hebridean type.	fB	44
4. *Mugearite*, dark grey, platy weathering trachybasalt, composed of olivine, oligoclase, orthoclase, clinopyroxene and iron-titanium oxides, normally exhibiting trachytic texture.	W^{M}	69
5. *Big-feldspar mugearite*, macroporphyritic mugearite basalt, with large phenocrysts of labradorite—bytownite in a mugearite groundmass.	fW^{M}	23
6. *Trachyte*, pale grey or white trachyte containing a few alkali-feldspar and ferromagnesian phenocrysts in a groundmass of alkali feldspar laths; shows trachytic texture.	T	14

prohibit inter-flow weathering. Nevertheless boles are very common in the North Skye sections and their presence demonstrates the extrusive origin of the doleritic Vaternish types, among others.

Detailed investigation of the boundaries between massive central layers and upper and lower carapaces has made it clear that the central layer is not a later intrusion. Chilled contacts are not found, nor has any sign of transgression been discovered. It is easily possible to demonstrate the petrographical identity of the rocks in all three layers, allowing for the alteration which has occurred in the amygdaloidal carapaces. Nevertheless, once the solid carapaces have formed the environment of a central layer is not unlike that of a shallow intrusive sill. It appears probable that in the case of the Vaternish type flows the carapaces were sufficiently impervious to conserve enough of the volatiles in the central portion to permit coarse crystallization to ensue; the feldspars in this type are as coarse or coarser than those in the thick sills intruded into the Jurassic sediments. The Vaternish type flows are nevertheless quite definitely extrusive, and exhibit the characteristic four-fold layering. This can be seen very well in the cliffs of Tianavaig Bay. Conservation of volatiles is also indicated by the presence of pegmatitoid segregations (see p. 112) in the Vaternish type flows. The suggested picture of the consolidation of a typical lava is, then, that a solid crust formed at the top and bottom surfaces of the flow as it moved, and that in some cases there was a considerable time-interval before the centre consolidated. If the centre solidified as a whole, prismatic jointing was produced as in a sill. Subaerial weathering, if sufficiently prolonged, produced a laterite-like soil on the top surface of the crust. Tropical conditions are not necessarily implied, since the internal heat of the cooling flow would contribute to the efficiency of the weathering process. While recent and present-day parallels for this process are easy to find in regions of current basaltic vulcanism, it may be noted that in Skye ropy (pahoehoe) or blocky (aa-aa) surfaces of lavas are seldom if ever to be observed. Presumably these are transient features, readily destroyed by weathering or concealed by later flows.

Petrography and chemistry of a stratified lava. To investigate the relations between the various layers listed above, the second lava flow of the main series exposed at Creag Mor was chosen. The section is as follows:

	ft
4. Red bole	1½-2
3. Purple amygdaloidal basalt	8
2. Massive basalt, columnar jointed	50
1. Amygdaloidal basalt, resting on bole above 1st lava	½-1

The rock of the massive layer (37873) is a microporphyritic olivine-basalt of Hebridean type, containing hypautomorphic or rounded olivines up to 1·5 mm diameter, set in a groundmass of plagioclase laths averaging 0·3 mm long. There are a few larger plagioclases which might be regarded as microphenocrysts, and in these conspicuous zoning, with cores having a maximum anorthite-content of 70 per cent, is displayed. The range in the typical groundmass plagioclase is approximately An_{62} to An_{66}. Augite, pale mauve under the microscope, encloses the feldspars in ophitic clots up to 1·5 mm in diameter. There are also small olivines, possibly of a second generation, and automorphic titanomagnetites of 0·05-0·15 mm in the groundmass. A little pale green chlorite is present, and olive-green bowlingite seams some of the olivine phenocrysts. Interstitial thomsonite and analcime are present, but in small amounts only. An analysis of this rock is given in column VI, Table IV.

Relics of a comparable texture are preserved in the overlying amygdaloidal rock (37874). Pseudomorphs in a highly magnesian chlorite (having $\gamma = 1{\cdot}54+$) after olivine are of the same dimensions as the olivine phenocrysts in the massive layer. The groundmass plagioclases again average 0·3 mm long, but they have been extensively attacked by chlorite. The interstices between the feldspars are filled with dark, iron-rich glass, with in places, skeletal, slag-like clinopyroxenes. It is noteworthy that no titanomagnetite crystals are to be found; their constituents are presumably in the glass and the implication is that they crystallize late in the magma. Numerous gas-cavities occur, lined with stilbite, chabazite, analcime and fibrous ?laumontite, as well as with chlorite. A channel sample was cut in order to determine the average composition of this rock, which is given in column VII, Table IV.

In the bole (37875) relics of the texture of the amygdaloid can be seen in

TABLE IV

Analysis of Hebridean Basalt, Amygdaloid and Bole

	VI	VII	VIII	D	E
SiO_2	45·99	42·40	34·27	46·12	44·15
Al_2O_3	14·65	14·66	19·72	15·46	15·49
Fe_2O_3	2·23	8·82	18·55	3·85	7·57
FeO	9·80	4·92	0·82	6·51	2·57
MgO	9·46	8·33	5·05	10·12	6·36
CaO	8·68	8·40	6·48	10·66	9·08
Na_2O	2·83	2·60	1·70	1·48	2·01
K_2O	0·46	0·30	0·32	0·65	0·31
$H_2O > 105^\circ$	2·34	3·68	6·31	2·38	5·80
$H_2O > 105^\circ$	1·38	3·76	3·51	1·01	4·90
TiO_2	1·90	2·09	2·71	1·37	1·35
P_2O_5	0·20	0·21	0·20	0·06	0·08
MnO	0·19	0·15	0·20	0·21	0·20
CO_2	tr.	tr.	0·01	—	—
S	0·02	0·01	tr.	tr.	—
Cr_2O_3	0·05	0·03	0·03	—	—
NiO	0·01	0·01	0·02	—	—
BaO	0·01	0·01	0·01	—	—
SrO^+	0·03	0·03	0·07	—	—
Li_2O	nt. fd.	nt. fd.	nt. fd.	—	—
	100·23	100·41	99·98	99·88	99·87

$^+$ Spectrographic determinations.

VI	Massive centre of 2nd Lava, Creag Mor, of Beal Point, Rubha na h'Airde Glaise, Skye.
VII	Upper Amygdaloid of 2nd Lava, same locality.
VIII	Bole above 2nd Lava, same locality.
D	Middle part of lava flow, Island Magee, Antrim.
E	Vesicular, zeolitic, upper part of lava flow, Island Magee, Antrim.

Analysts: VI, VII, VIII, W. F. Waters and K. L. H. Murray, Geological Survey Lab. Nos. 1577, 1578, 1579, (1951), Guppy and Sabine 1956, pp. 27, 28. D, E, W. H. and F. Herdsman *in* Tomkeieff, 1934, p. 502.

patches, surrounded by dense red iron oxide. There are also a few rounded grains of fresh calcic plagioclase, microcline, quartz and clinopyroxene which must be regarded as detrital. A small area in the slice shows basalt of finer grain-size than the average for the flow, but with better-crystallized clinopyroxene than in the upper amygdaloid. Irregular cracks in the bole have been infilled with a mosaic of fine-grained quartz. The composition of an average sample is given in column VIII, Table IV.

The principal chemical differences between the centre and the upper carapace are (i) a major increase in ferric at the expense of ferrous iron in the latter; (ii) a sharp rise in water-content; (iii) an appreciable decrease of lime and silica and small decreases in alkali-content. A comparison of the middle and the amygdaloidal top of a Hebridean-type lava described by Tomkeieff (columns D, E in Table IV), shows differences of the same type and order, except that soda is higher in the amygdaloid here. In both instances alumina remains constant. The strongly oxidized state of the iron suggests either the influence of atmospheric oxygen, or the initial presence of iron-bearing minerals which were more susceptible to the effects of later weathering than those in the massive centres.

The conversion of amygdaloid into bole is accompanied by a further sharp rise in ferric oxide, and the elimination of most of the remaining ferrous oxide. Following the pattern of lateritic weathering, alumina rises at the expense of lime, magnesia and silica, notwithstanding the presence of free silica in the bole. In some cases the texture of the lava can be discerned in the bole (for example 37919, 37920, Storr; 37877, 37878, 37879, Hartaval; 37946, 37947 Vaternish type, R. Chracaig); but in other cases the texture is totally destroyed (for example 37880, 37885, Quirang; 39100, 39101, mugearite, Hartaval).

At one time it was supposed that a mineral species called plinthite existed in certain boles (Thomson 1836; Heddle 1882, 1883). Re-examination of some of the material by J. M. Sweet (1960) shows it to consist of mixtures of zeolites and haematite; but the type specimen is a montmorillonitic clay with haematite and a little analcime.

PETROGRAPHY OF HEBRIDEAN TYPE OLIVINE-BASALTS

The rocks of the Hebridean type olivine-basalts include green to black trappides from the central portions of the flows, and pale grey, purple or greenish amygdaloids from the upper and lower carapaces. In the trappides, small amygdales are seldom entirely absent, but usually they do not constitute an important part of the rock. In most cases the texture of the central portion shows a considerable measure of consistency, but in a few instances, coarse segregations, to which the term pegmatitoid (Lacroix 1928, Dunham 1933) is applicable, can be found. These are taken to represent pockets where accumulated volatiles slowed down the rate of crystallization. In shape they are often irregular but there is a tendency to form flat-lying schlieren. In the trappides the olivine phenocrysts, which are a universal feature of the type, can in some cases be seen with the naked eye.

The amygdales contain zeolites, chlorite and green mineraloids of the kind that petrographers at one time called viridite, and which would come within Peacock's (1930) definition of chlorophaeite, though not necessarily exhibiting the colour-change on exposure associated with that material in some dolerites. These late minerals and mineraloids are discussed in a separate section below.

There is little doubt that the amygdaloids are very much more susceptible to alteration by superficial weathering than the trappides; indeed this is the reason for the step-featuring which is such a characteristic part of the scenery in the lava country. Thus the mineral composition of the amygdaloids may well differ at surface from that to be found underground. In the absence of specimens from borings, however, it is not possible to ascertain this directly.

From microscopical evidence, the Hebridean type lavas are to be classed as olivine-phyric, olivine-basalts, generally carrying a mesostasis of zeolites. The essential pyrogenic minerals are olivine, clinopyroxene, plagioclase and titano-magnetite; each species will be considered in turn.

Olivine is present as phenocrysts in all the lavas of this type. Previous descriptions of the Plateau type lavas, other than that in the Ardnamurchan Memoir (Richey and Thomas 1930, p. 114) appear to lay insufficient stress upon the existence of what is plainly an early generation of this mineral. In the hand specimen the olivine is yellowish-green to green, but in thin section it appears colourless. The crystals may have well-developed automorphic faces (31302, 31313, 31345, 31408, 31420, 31595) or the habit may be tabular or platy (36194, 36206, 37914). Far more commonly, however, the olivine phenocrysts show rounded outlines, and this may be regarded as the normal case. In diameter they range from 0·25 mm up to 3·5 mm, but a scatter-diagram based on measurements on all the available slices shows a strong maximum for the range 0·5-1·0 mm and a subsidiary peak at 2·0 mm. These olivines are classed as phenocrysts because they fail to enclose either plagioclase or pyroxene crystals. They do, however, enclose tiny automorphic crystals of titano-magnetite, even when perfectly fresh, and it appears necessary to assume that at least some of the iron-titanium oxide crystallized early, unless the oxides were introduced by replacement, which appears unlikely.

There can be little doubt that this generation of olivine had already crystallized before the basalt magma was extruded, and that the rounding of the crystals is due to abrasion while they were being carried in suspension. There is however, in many of the basalts, though not in all, evidence of a second generation of olivine crystals, rarely exceeding 0·1 mm in diameter. These can be seen to enclose feldspars and they are often enclosed in clinopyroxene plates. The aggregate quantity of olivine of the second generation is usually less than that of the porphyritic kind; for example in a Hebridean basalt from Score Horan (37987) olivine phenocrysts make up 17½ per cent by weight of the rock, while second generation olivine amounts to less than 10 per cent. However, there are exceptional cases where the latter exceeds the former; another lava from Score Horan (37990) contains 6 per cent phenocrysts, and 21 per cent second generation olivine.

Estimates of the composition of the olivines have been made by the immersion technique of refractive index measurement. This method is regarded as preferable to the measurement of apparent optic axial angle by means of the universal stage, as advocated by Tomkeieff (1939) and used in recent investigations of olivine in the Shiant Islands Sill by R. Johnston (1953). As will be evident from the table given by the former author (Tomkeieff 1939, p. 235), in the highly magnesian olivines a variation of 1° in 2H corresponds to 11, 7 and 5 per cent of fayalite in the range from 0 to 23 per cent Fa. As the apparent optic axial angle is not directly observable in this range (see for example the strictures of Hess (1949) on indirect measurement of 2H, which accord with our experience) this can only be an inaccurate procedure for the determination of magnesian olivines. On the other hand, according to recent refractive index data (Deer and Wager 1939; Winchell 1951), a range of 0·002 in β (the accepted limit of error in immersion measurement) corresponds to less than 2 per cent fayalite-content. The procedure adopted here was to use bromoform concentrates of the ferromagnesian minerals from the lavas investigated. In all but a few cases, the olivine grains were readily distinguishable from the coloured clinopyroxenes. Determinations of β on oriented grains, and of the maximum and minimum refractive indices on some hundreds of grains in each powder then indicated the range of olivine composition present. That a range exists is shown by the results given in Table V: It arises from two causes: (1) zoning; (2) differences in composition between first and second generation crystals. Observation on sections showing an optic axis normal to the section seldom reveal much evidence of zoning in the Hebridean basalts (though this is very evident in the mugearites) and it is considered that cause (2) is the more significant. The olivines of the Skye Hebridean basalts shown an extreme range from Fa_{13} to Fa_{30}, but the average composition is in the vicinity of Fa_{20}.

In the trappide centres, much of the olivine is fresh, but it is seldom completely unaltered. Various alteration products occur. Highly birefringent green bowlingite may form fringes and fill cracks traversing the mineral (31311, 33824, 33872). Occasionally olivine is rimmed with golden-yellow xylotile (37914). Reddish-brown iddingsite occurs in a similar way, and may result from the oxidation of bowlingite (31383, 31457, 31461, 32465). Complete or partial replacement of olivine by iron oxides, probably a mixture of magnetite and haematite, is occasionally seen (31425, 33806). Carbonates, including calcite (31304) may also pseudomorph the olivine but this is far less common in these rocks than in many older lavas. Probably the most widespread type of alteration of olivine is to a low-birefringence magnesian chlorite (37884, 37889) and in some cases the chlorite has brown margins, as if representing a thin outer zone in the olivine where the iron-content was greater (37885). In the amygdaloids, olivine has usually been completely altered, either to chlorite, or to a dirty green mineraloid (37980).

The plagioclase occurs as a mesh or network of slender laths ranging up to 0·5 mm long. In a few cases, they are arranged in a fluxion texture (37970), 38006) but this is unusual and it appears likely that the magma was stationary before much feldspar crystallized. In composition the plagioclase lies within the labradorite range and the crystals usually show distinct zoning. The estimates of composition given in Table V are based on refractive index measurements in powders from the light fractions in bromoform. In the other slices examined, observations of extinction angles and other optical properties suggest a similar range, with occasionally an outer zone more sodic than those in Table V. Except where they have been attacked by zeolites, which embay the margins and penetrate along cleavages and twin planes (36194-7, 36225) the feldspars are fresh and clear in the trappide centres. Albitization is extremely rare and was proved in a single instance only (31460).

The pyroxenes all belong to the augite group as restricted by Hess (1949); all show extinction angles in the range 40-45°, and repeated observations failed to reveal a single instance of a pyroxene with optic axial less than 40°. The clinopyroxene from lava 12 of The Storr sequence (Table V) (37909) was found to have $2V = 52°$, $\beta = 1{\cdot}700$; corresponding with a sub-calcic augite. This

TABLE V

MINERALS IN LAVAS EXPOSED AT THE STORR AND RUBHA NA H-AIRDE GLAISE
(One-inch Sheet 80, six-inch Sheet Skye 18 N.W.)

Lava No.	Slice No.	Symbol One-inch map	Olivine % Fa	Plagioclase % An	Mode, Wt %					
					Ol	Py	Pl	Mt	Ch	Z
S										
24	37922	W^M	32–35	32–20	2	23	48	25	1	—
23	37921	oB	24–30	55–30						
22	37919	oB	19–20	54–48						
21	37918	oB	19–24	68–57						
20	37917	oB	18	69–55						
19	37916	oB	18	66–52						
17	37915	oB	25	64–57						
16	37914	oB	18							
15	37913	Bc		70–62						
14	37912	Bc	20	70–						
13	37911	oB		66–						
12	37909	oB		65–55	5	28	43	7	16	1
11	37908	oB	13–20	66–	24					
10	37907	fB		68–58	1	17	27	8	37	10
9	37906	oB	18–20	70–58	16	31	35	15	2	—
8	37905	oB	16–20	66–	23	29	33	10	3	2
7	37904	oB	19	70–55	13	25	44	11	1	6
6	37903	oB	18–20	67–60	19	25	36	9	11	—
5	37902	fB	19–25	75–65						
4	37900	oB	19–20	67–	14					
3	37899	oB^+	19–26	45–20	14					
2	37898	oB	20–25	65–	19	25	40	9	6	—
1	37896	oB	21–25	68–	5	23	53	6	13	—
R										
6	37975	oB	24	56–	17	32	34	6	—	11
5	37974	oB	18–24	64–	14	24	48	10	—	4
4	37973	oB	17–		18	24	39	11	—	8
3	37970	oB	18–21	60–	15	20	48	14	—	3
1	37968	oB	18	55–	20	19	50	5	—	6

R = Cliff section $\frac{1}{3}$ mile N. of Rudha na h'Airde Glaise.
S = Storr; nos. 1-13 in cliff S. of Coire Faoin; nos. 14-24 in southermost gully on main east face.

Under mode the symbols used are as follows (figures in brackets assumed densities): Ol–olivine (3·3); Py–pyroxene (3·3); Pl–plagioclase (2·7); Mt–titanomagnetite (5·0); Ch–chlorite (2·6); Z–zeolites (2·1).

may be compared with the properties of a purple pyroxene separated from a pegmatitoid patch in lava 4 of the same sequence (37901), which showed $2V = 50°$, $\beta = 1{\cdot}706$, possibly nearer the augite-ferroaugite boundary (see Hess 1949) than the previous example. Owing, however, to the effect of Ti and Al upon their optical properties, it is not proposed here to attempt a closer definition of the composition of the pyroxenes of the basalts.

In colour the clinopyroxenes show considerable variation. Of 155 slices examined for the purpose, 64 showed augite of a definite purple or mauve tint (of the shade usually supposed to denote the presence of Ti); 59 were in shades of brown, pale brown and yellow; 7 were distinctly green, while to our eye, 25 were colourless. Thus it is certainly not true to say that purple augite is characteristic of the Hebridean lava type; nor is there any correlation between this colour in pyroxene and the presence or absence of an abundant zeolitic mesostasis in the rock.

In habit the clinopyroxenes also vary considerably. A well defined ophitic habit, whereby a single crystal of augite envelops many feldspar laths in diverse orientations, was noted in exactly half of the 214 slices examined. Of the remainder, 31 were intersertal or subophitic, and 71 intergranular. The ophitic crystals commonly reach 2·5-3·0 mm in diameter; granules, on the other hand, nestling in clots between the feldspar laths, rarely exceed 0·25 mm diameter.

The opaque minerals have already been mentioned as occurring as tiny euhedra included in the olivine phenocrysts. These rarely exceed 0·05 mm in width. Opaque minerals also form elongate plates and hypautomorphic grains intergrown with the feldspar and pyroxene, usually somewhat larger than the inclusions in the olivine, but rarely exceeding 0·25 mm in their greatest dimension. A polished section of the analysed rock (37873) on examination at high magnification showed that the opaque constituent is silver-grey in reflected light and homogeneous. It proved to be completely isotropic and is distinctly magnetic. It is therefore identified as titanomagnetite[1], for, having regard to the TiO_2 content of the rock (p. 110) it is very probable that it carried $FeTiO_3$ in solution, and that the rate of cooling has been such as to inhibit unmixing. Another example (37877), from Bealach Hartaval, showed similar homogeneity. However, the coarser magnetite from a pegmatitoid in lava no. 4 of The Storr sequence (37901) proved to contain lamellae of exsolved anisotropic ilmenite, a further illustration of the slow rate of cooling in these coarse segregations.

It remains to consider the mesostasis of the Hebridean type lavas. Examples of rocks entirely composed of the pyrogenic minerals listed above are very rare, though occasionally an example can be found where the only other constituent is chlorite, in very small amount (37898, 37928). The normal situation is, however, that pockets of zeolites and of chlorite occur in the angular spaces between the feldspar laths. Among the zeolites, the commonest are analcime, thomsonite and chabazite. Analcime forms clear and cloudy pools which may be completely isotropic, or which may exhibit feeble birefringence. The refractive index is close to 1·490 and faujasite and levynite may also be present; indeed on chemical grounds these calcic zeolites would be expected rather than analcime. Distinction from chabazite is also difficult unless the rhombohedral cleavage or crystal outline of this mineral can be seen (37885, 37891). Thomsonite forms groups of fibres showing characteristic Y-elongation. In a pegmatitoid from Quirang

---

[1] In the sense in which this term is used by Chevalier, Bolfa and Mathieu 1955).

(37882) the phyllosilicate gryolite was identified; this occurs with zeolites at other localities described below and it may be a more frequent constituent of the mesostasis than has been supposed. The chlorites vary considerably in colour from bright green in thin section to nearly colourless. Magnesian types with positive elongation, birefringence of 0·005 or less, and refractive index 1·60-1·61 are commonest (e.g. 37896, but occasionally examples with higher birefringence can be found e.g. 37903).

The pegmatitoids (37582, 37901, 37910) associated with the Hebridean type lavas differ from the lavas both in composition and texture. The most striking feature is the total absence of olivine, showing that these patches formed when the physicochemical conditions for the separation (probably the necessary high temperature) no longer existed. The pyrogenic minerals are clinopyroxene (as indicated above, probably somewhat more ferriferous than the augite of the lavas), plagioclase which may be as sodic as oligoclase, magnetite with ilmenite lamellae, and abundant analcime, thomsonite, chlorite and other hydroxyl-bearing minerals. Pyroxene and plagioclase may reach 5 or even 10 mm long.

Composition of the Hebridean type lavas. Few of the Hebridean-type lavas are free from zeolites and chlorite and the centre of the 2nd lava of Creag Mor (37873), a chemical analysis of which has already been cited (p. 103), is representative of the type. In Table VI this is compared with other Skye olivine-basalts, and C.I.P.W. norms are given. It is interesting to note that the normative feldspar (An_{52}) is decidedly more sodic than the range of composition deduced from optical measurements ($An_{62\text{-}70}$), showing that the Na/Ca ratio is higher in the zeolites (chiefly analcime and thomsonite) than in the plagioclase.

The mode of the rock, measured by means of a count of 4100 points, gave the following results in volume per cent; Plagioclase, 43; Zeolites and Chlorite, 10; Pyroxene, 28; Olivine, 12; Titanomagnetite, 7. The result shows a poor correspondence with the norm, but measurement of a second section gave almost identical figures, and measurement by a second observer provided further confirmation. The discrepancy, a tendency to obtain low results in the mode for light minerals, high results for the dark, is considered to be due to the overlap effect in this fine-grained rock, where the feldspars average only 0·3 mm long (see for example Chayes, 1956), causing pyroxenes to overlie feldspar within the thickness of the slide. The modal figures given in Table V must therefore be treated with caution; it seems certain that they have no more than a general comparative value, though it is believed that the estimates of olivine-content can be relied upon.

An attempt to find a rock free from hydroxyl-bearing minerals for the purpose of investigation being carried on by Professor C. E. Tilley showed how difficult this is to achieve. However, one such rock was discovered, and the analysis (Muir and Tilley 1962, p. 212) and the norm are quoted in Column IX, Table VI. The rock (43948) contains tabular, slightly corroded olivines up to 1 mm long, set in a basaltic framework of 0·3 mm plagioclase, intergranular and subophitic pale augite, and titanomagnetite.

These figures raise the question of consistency within individual lava flows. Tomkeieff (1934) has demonstrated a measure of gravitative differentiation within a basalt probably allied to the present suite at Island Magee. No comparable case has been found during the present survey, but in several instances pairs of specimens from different parts of the same flow gave closely similar modal

TABLE VI

Analyses and Norms of Hebridean Type Basalts, Skye

Analysis

	VI	IX	F	G	H
SiO_2	45·99	46·12	46·61	46·38	45·68
A_2l_3O	14·65	13·94	15·22	16·77	14·66
Fe_2O_3	2·23	1·95	3·49	3·22	2·88
FeO	9·80	10·46	7·71	8·03	9·67
MgO	9·46	11·08	8·66	8·83	9·82
CaO	8·68	9·05	10·08	10·68	9·37
Na_2O	2·83	3·11	2·43	1·94	2·14
K_2O	0·46	0·57	0·67	0·10	0·19
H_2O+	2·34	1·49	2·07	2·46	3·43
H_2O-	1·38	0·40	1·10	0·37	0·36
TiO_2	1·90	1·81	1·81	1·04	1·65
P_2O_5	0·20	0·23	0·10	0·08	0·07
MnO	0·19	0·18	0·13	0·24	0·22
CO_2	tr.	—	tr.	nil	nil
S	0·02	—	—	—	—
Cr_2O_3	0·05	—	tr.	—	—
NiO	0·01	—	tr.	—	—
BaO	0·01	—	—	—	—
SrO	0·03	—	—	—	—
	100·23	100·39	100·08	100·14	100·14
Specific Gravity			2·87	2·84	2·97

Norm

		VI		IX		F		G		H	
or		2·8		3·3		3·9		0·6		1·1	
ab		23·6		21·0		20·4		16·2		17·7	
an		28·8		22·4		28·6		37·0		30·1	
ne		—		2·8		—		—		—	
di	wo	6·8	13·3	9·3	18·0	8·6	16·5	6·4	12·4	6·6	12·8
	en	4·1		5·7		5·7		4·0		4·1	
	fs	2·4		3·0		2·2		2·0		2·1	
hy	en	3·1	5·0	—		6·9	9·7	11·8	17·6	10·2	15·7
	of	1·9				2·8		5·8		5·5	
ol	fo	11·5	18·6	15·4	24·3	6·2	·89	4·3	6·8	7·1	11·2
	fa	7·1		8·9		2·7		2·5		4·1	
mt		3·3		2·9		5·1		4·6		4·2	
il		3·5		3·5		3·5		2·0		3·2	
ap		0·3		0·3		0·3		0·3		0·2	
Feldspar		$Or_5Ab_{43}An_{52}$		$Or_7Ab_{45}An_{48}$		$Or_7Ab_{39}An_{54}$		$Or_1Ab_{30}An_{69}$		$Or_2Ab_{36}An_{62}$	

KEY TO TABLE VI

VI Olivine-basalt, Creag Mor, cliff W. of Beal Point, Rubha na h'Airde Glaise, Skye. Analysts: W. F. Waters and K. L. H. Murray, Geological Survey Lab. No. 1577 (1950), Guppy and Sabine 1956, p. 27.

analyses. For example, two specimens from the lowest exposed lava, 50 ft thick, at Maoladh Mor, Quirang, showed:

		ol	py	pl	mt	ch
37781	18 ft above base	24	28	38	8	2
37780	near base	24	28	37	10	1

In spite of the consistencies shown by the analyses of the Hebridean 'plateau' lavas, there is a good deal of variation in their olivine-content, as might be expected from the presence of a pre-extrusion generation of this mineral. This is illustrated by the modal measurements in Table V, and also by the results for lavas from the well-exposed cliff section at Biod a'Ghoill, Score Horan, Vaternish (Table VII, p. 112).

PETROGRAPHY OF VATERNISH HEBRIDEAN TYPE LAVAS

In texture the rocks of Vaternish type are olivine-dolerites containing, by definition, plagioclase which exceeds 0·5 mm in average length. The olivine again occurs in two generations (e.g. 36199) but its porphyritic character is less obvious since the size of the crystals remains the same as in the Hebridean type, while the later feldspars reach lengths comparable with those of the olivines. Measurements on the 42 available slices showed that the range of size, 0·1 to 3·5 mm, is identical with that of the Hebridean type, while there is again a distinct maximum for the range 0·5 to 1·0 mm. The few measurements made suggest that the composition-range is also similar and again in these rocks, there is little obvious evidence of zoning in the olivines.

The clinopyroxenes are again augites, with optic axial angles exceeding 40°. The faintly green pyroxene, for example, in the lava exposed at the foot of the main cliff at The Storr (37912) has refractive index $\beta = 1{\cdot}699$, and $2V = 46\frac{1}{2}°$. No pigeonite was found in the Vaternish type lavas. An ophitic habit is more widespread in this type but it is by no means universal. Altogether 27 examples examined were ophitic, 6 subophitic or intersertal, and 8 intergranular. In colour there was a more marked tendency towards purple tints in the augite, over half the examples studied showing this characteristic while only two were green and two brown.

The range of plagioclase composition is An_{55} to An_{70}, but the larger part of each of the zoned crystals generally corresponds with the more calcic range of the labradorite division. In a few cases, cores of bytownite have been noticed (e.g.

KEY TO TABLE VI *continued*

IX Olivine-basalt, quarry on W. side of road near Achtalean, 2¼ miles N.N.W. of Portree, Skye; Geological Survey slice 43948. Analyst: J. H. Scoon (1960). Muir and Tilley 1962, p. 212.

F Olivine-basalt, near bridge over Allt Fionnfhiachd, Drynoch Skye. Analyst: W. Pollard (1899). Quoted from Harker (1904, p. 31).

G Fine-grained basalt, 100 yd N.W. of Loch Cuil na Breig, Skye. Analyst: W. H. Herdsman. Quoted from King (1953, p. 365).

H Basalt with ophitic texture, 50 yd W. of Strollamus Quarry, Skye. Analyst: W. H. Herdsman. Quoted from King (1953, p. 365).

31381). In size, the tabular crystals range up to over 3 mm across (e.g. 38011) in this group but the normal average is between 0·5 and 1·5 mm. The feldspars, as in the finer-grained basalts, form a mesh, the interstices of which are partly filled with granular ophitic augite, and partly with zeolites and chlorite. The attack upon the feldspar by zeolites, particularly members of the analcime group, is more obvious in these coarse rocks than in the Hebridean basalts (e.g. 32477, 32482, 32489), though it is seldom as severe as in some of the intrusive teschenitic dolerites described in Chapter VIII.

The zeolites in the mesostasis include, besides analcime, well-developed thomsonite (31406, 32917), and chabazite (37904).

Notwithstanding the slower rate of cooling which the coarser texture of the Vaternish type lavas may be taken to indicate, the opaque constituent is again homogeneous titanomagnetite in the typical example examined in polished section (37912), showing no sign, even at high magnification, of unmixing. The titanomagnetite crystals share in general the coarser texture of the rock as a whole, and occasionally reach as much as 0·5 mm across (31399).

Pegmatitoid segregations are, as might be expected, well developed in the Vaternish lavas. A good example can be seen at the top of the prominent feature which encircles Ben Tianavaig, S. E. of Portree. The feature is formed by a Vaternish type basalt (37930) in which horizontally disposed, coarse segregations occur near the top of the hard portion (37931). The feldspar in these is conspicuously albitized; the brown augite and titanomagnetite are both coarse, and much analcite and thomsonite are present. In another example, from Quirang (37887), the feldspar is oligoclase but it appears to have crystallized as such. Apatite is seen in this rock. Zeolitization of the plagioclase is a normal feature of these rocks (e.g. 38002).

In addition to zeolites, chlorite is widespread as a late hydroxyl-bearing mineral. In a single instance (30683) a little green amphibole has been detected, but this serves to emphasise that for the most part the conditions during the later stages were not suitable for the formation of minerals of this group; probably the pressure was too low.

TABLE VII

MINERALS IN LAVAS EXPOSED AT BIOD A'GHOILL, SCORE HORAN, VATERNISH

Lava No.	Thickness Ft.	Slice No.	Symbol one-inch map	Mode, Wt per cent				
				ol	py	pl	mt	ch
14		37993	W^M	15	13	53	19	—
13		37992	oB	20				
12		37991	oB	13				
11		37990	oB	26				
9	25	37987	oB	28				
8	28	37986	oB	13				
7	36	37985	oB	19				
6	25	37984	oB	13	35	38	4	10
5	44	37983	fB	11	29	44	13	3
4	24	37982	oB	33				
2	56	37979	oB	17				

No new chemical analysis of a rock of the Vaternish type has been made but we would regard both the analysed rocks of the 'Great Group of Dolerite Sills' (8057, 7854) cited by Harker (1904, p. 248) as members of this group. The general similarity of these analyses with those of the Hebridean type is at once apparent, though the alkalis in the Broc-bheinn rock (Na_2O 3·58; K_2O 1·19) are somewhat higher than normal.

There is, however, little justification for any suggestion that lavas of the Vaternish type crystallized from basaltic magma significantly different in composition from that producing the Hebridean-type lava. The coarser texture is, we suggest, due to a more effectively sealed outer carapace during crystallization. The division between the types is admittedly an arbitrary one, useful for the identification of mapping horizons, and valuable when a distinction is to be drawn between extrusive basalt and dolerite; but without fundamental significance.

Zeolites associated with the Hebridean and Vaternish Hebridean type basalts. Northern Skye has long been renowned among mineralogists for the beauty and variety of the zeolites and associated minerals to be found in cavities in the lavas. During the second half of last century M. F. Heddle published chemical analyses of nearly all the species found here, and these were collected together in the posthumous volume edited by Goodchild (Heddle 1901).

In connection with the present work, small collections of these zeolites in the possession of the Geological Survey and the Durham University Geology Department (prefix D) have been investigated by optical and in some cases X-ray methods, with the results summarized below.

Analcime occurs in trapezohedral crystals up to 2 cm in diameter at The Storr, in cavities exposed on the main cliff face in a Vaternish-type lava. The optical properties are anomalous (D. 2417), though a normal X-ray powder pattern has been obtained. The refractive index is 1·481 but in birefringent areas the high index is 1·491. In a vesicle in lava no. 8 of The Storr sequence (37905) the analcime, with refractive index close to 1·493, show polysynthetic twinning and is appreciably birefringent. Complex twinning is also seen in a specimen from Quirang with typical analcime morphology, and $n = 1{\cdot}489 - 1{\cdot}491$. The difficulty of distinguishing birefringent analcime, which appears to be common in these lavas, from faujasite and chabazite has already been mentioned. The new mineral wairikite (Steiner 1955) may be present (it is stated to show polysynthetic twinning) but the whole group of minerals appears to require further investigation.

Chabazite forms clusters of rhombohedra up to 5 mm on the side. A specimen from The Storr (D. 2413A) gave refractive indices, $\alpha = 1{\cdot}485$, $\gamma = 1{\cdot}490$. A cavity from the amygdaloid overlying the 4th lava of the Quirang section (37886) proved to be lined with chabazite showing $\alpha = 1{\cdot}490$, $\gamma = 1{\cdot}494$. According to the data summarized by Winchell (1951, p. 334) these chabazites lie near the calcic end of the series. Variable optic sign and optic axial angle is a characteristic feature. Rhombohedral cleavage is noticeable in thin section, and provides a means of distinguishing the mineral from analcime.

Thomsonite forms white or bluish compact fibrous masses in many specimens. An example from The Storr (D. 2413) showed Y-elongation, parallel extinction, positive optic sign, $\alpha = 1{\cdot}521$, $\beta = 1{\cdot}526$, $\gamma = 1{\cdot}531$. Another (2416) showed $\alpha = 1{\cdot}517$, $\beta = 1{\cdot}522$, $\gamma = 1{\cdot}526$. Heddle (1901, p. 110) gave the following analysis of a specimen from The Storr: SiO_2 39·02; Al_2O_3 28·13; Fe_2O_3 3·28; CaO 10·73; K_2O 1·01; Na_2O 3·71; H_2O 13·99; Total 99·87. He also quoted several analyses of a variety called faroelite, the composition of a Storr specimen being: SiO_2 41·32; Al_2O_3 28·44; CaO 11·54; Na_2O 5·77; H_2O 13·26; Total 100·33.

Stilbite occurs as white or cream-coloured radiating bundles. At The Storr (D. 2413) the mineral has negative sign, low 2V, $\alpha = 1{\cdot}493$, $\gamma = 1{\cdot}509$; $X \wedge C = 9^\circ$. The birefringence is unusually high, but similar properties were shown by another specimen (2415). In a third (2419C), $\alpha = 1{\cdot}495$, $\gamma = 1{\cdot}504$, $X \wedge C = 4^\circ$. In the basalts the mineral appears to be found chiefly in large cavities, rarely in the mesostasis of the rock, but as mentioned below, extensive replacement of the feldspar of a trachyte by stilbite has been found.

Laumontite occurs both at the Quirang and The Storr as delicate fibres which prove under the microscope to be very elongated plates showing 'hour-glass' type twinning. The optical properties of a Quirang specimen are: optically negative, $2V = 25^\circ$; $\alpha = 1{\cdot}514$, $\gamma = 1{\cdot}525$, $Z \wedge C = 19\text{-}23^\circ$. Heddle (1901, p. 91) gave two analyses of laumontite from Storr, one of which showed SiO_2 51·98; Al_2O_3 20·34; Fe_2O_3 0·59; CaO 11·55; H_2O 15·78; Total 100·24. This, he stated, came from a vein 1½ in in thickness.

Mesolite from The Storr (2420) forms fine white hair-like fibres (Heddle described them as 'plumose tufts'). They have birefringence not above 0·001, refractive index close to 1·505. Heddle (1901, p. 108) analysed a specimen from this locality: SiO_2 56·72; Al_2O_3 26·70; CaO 8·90; Na_2O 5·40; H_2O 12·92; Total 100·63.

Levynite, in colourless platy crystals, uniaxial negative with $\omega = 1{\cdot}502$, $\epsilon = 1{\cdot}498$ occurs at The Storr (D.2419B). Heddle (1901, p. 96) gave an analysis from the Quirang: SiO_2 43·13; Al_2O_3 21·77; FeO 1·38; CaO 9·25; K_2O 0·95; Na_2O 3·44; H_2O 20·20; Total 100·12.

Apophyllite $KCa_4\ FSi_4O_{10}.8H_2O$, though not a zeolite is intimately associated with analcime, chabazite, thomsonite and laumontite at Quirang. The crystals are cubes with pearly lustre, and show penetration-twinning. Under the microscope many crystals are isotropic but a few show ultrablue or low-order grey interference colours. The refractive index is 1·539. A specimen from The Storr (2419A) with thomsonite showed $n = 1{\cdot}540$. Heddle analysed a specimen from The Storr; SiO_2 51·2; Fe_2O_3 1·09; FeO 1·09; MnO 0·05; CaO 23·13; K_2O 5·49; Na_2O 0·37; H_2O 17·02; F 0·7; Total 99·89. The occurrence of this mineral is particularly interesting as revealing the availability of fluorine in hydrothermal fluids associated with the basalts.

Gyrolite $H_2Ca_2SiO_3{\cdot}H_2O$, a phyllosilicate, occurs in white or bluish-white radiating groups of plates at the Quirang, The Storr and elsewhere. A specimen from The Storr (2420) is almost uniaxial, negative, with $\omega = 1{\cdot}540$. Anderson (1851) gave the following composition for a specimen from Storr: SiO_2 50·70; Al_2O_3 1·48; MgO 0·18; CaO 32·24; H_2O 14·18; Total 99·78.

Other minerals found in the cavities include calcite with $\omega = 1{\cdot}660$; a platy mineral, biaxial negative with low 2V, $\alpha = 1{\cdot}495$, $\gamma = 1{\cdot}512$, inclined extinction 10°, possibly epistilbite (Quirang); and, according to Heddle, scolecite, but this has not so far been found in the collections investigated.

Heddle's doubtful species uigite has been reinvestigated by J. M. Sweet (1959) and found to be a variety of thomsonite. She has also described (Sweet 1961) hydrated calcium silicates including tobermorite, xonotlite and a new member of the tobermorite group, from a quarry on the Staffin road, ½ mile N. of Portree. The new mineral has the composition: SiO_2 41·8; Al_2O_3 5·6; Fe_2O_3 0·3; MgO 3·2; CaO 33·6; Na_2O 0·6; K_2O 0·1; $H_2O + CO_2$ 15·2. It has been named tacharanite. Saponite is associated in the same paragenesis.

With regard to the order of crystallization, there is evidence in many cases that the zeolites crystallized later than chlorite; for example in the Vaternish type lava at The Storr (37912) rouleaux of chlorite have been broken up and enclosed in analcime and thomsonite; in many basalts (e.g. 37911) chlorite forms the initial lining of cavities, which have a later filling of fresh zeolites (levynite in 37911). Feldspars protruding into cavities in pegmatitoids (37910) have been coated with chlorite before crystallization of analcime and thomsonite commenced. In another case (37930-1) there may have been an alternation of feldspar and zeolite formation, for the cores of zoned oligoclase crystals have been extensively replaced by analcime and chlorite, while albite outer zones are clear and unaffected. Mesolite is later than analcime and thomsonite in this rock. In crystal-lined cavities, analcime or thomsonite tend to be early minerals, chabazite, stilbite, laumontite and levynite later, and mesolite latest of all.

The time of crystallization of the zeolites poses an interesting question. Their interstitial position in the solid basalts suggests that they filled an open mesh of pyrogenic minerals not long after these crystallized. It is, however, clear that zeolites migrated widely in the lava-pile; for example a red bole (37921) at The Storr contains fresh stilbite and analcime which must have been introduced after the weathering process; while examples can be found in the cliffs N.E. of Portree of veinlets of zeolites which cut through more than one lava flow. Empty vesicles in the lavas are uncommon, though partly-fllled examples, some of which may show the level of a standing liquid at the time of mineralization, are occasionally found (D. 2450). Against this it may be recalled that modern lavas, for example in Iceland and Hawaii, show empty vesicles. The process of movement of hot waters through the lava-pile must be conceived as long-continued.

PETROGRAPHY OF FELDSPAR-PHYRIC OLIVINE-BASALT

The feldspar-phyric basalt group is also to be regarded as a variant of the Hebridean type, to which it is evidently closely related. It differs from the Hebridean type only in containing small phenocrysts of plagioclase, probably the result of pre-extrusion crystallization of this mineral. The phenocrysts are normally within the microporphyritic range, i.e. up to 2 mm long, (e.g. 31315, 31389, 31423, 37902) but a few examples have been found with phenocrysts up to 3 or rarely 5 mm long (e.g. 32305, 32467, 32830, 37907). It should be noted that the 'big-feldspar' rocks which are common between Bracadale and Mugeary, have a trachybasaltic groundmass, and are not included in the present group. In composition the plagioclase is usually a basic labradorite, occasionally with bytownite inner zones (32932, 33995), but it is not as a rule markedly out of phase with the groundmass plagioclase. The phenocrysts are seldom automorphic or complete; they appear to have been broken up during transport in the magma.

The plagioclase of the groundmass ranges up to 0·2 mm long and has a composition only slightly more sodic than that of the phenocrysts. The texture is identical with that of the Hebridean basalts, save that in a rock from the second flow below the summit of Healaval Bheag (38095) it has an orthophyric rather than basaltic appearance. Olivine phenocrysts ranging up to 3·0 mm diameter, in shape automorphic or rounded, are present as in the Hebridean lavas; usually they are more abundant than feldspar phenocrysts. A second generation can often be distinguished.

There seems to be a greater tendency for the augite in the feldspar-phyric basalts to be intergranular rather than ophitic; 20 examples were found to belong to the former category, while only 6 were found to be ophitic. It is not, however, certain that these figures are significant. In a single instance, augite, as well as feldspar, was found to be porphyritic (32932). Well-formed phenocrysts of about 2 mm long occur in this rock, and there is also a second generation of clinopyroxene granules of about 0·05 mm.

Titanomagnetite is present, commonly within the size-range 0·01-0·05 mm. A mesostasis variously of chabazite (31315), analcime (31352) and fibrous zeolites (32467) is found to occur.

No analysis of a member of this group has been made, but it is perhaps appropriate to comment that it is doubtful whether the proportion of feldspar phenocrysts is sufficient, in any of the North Skye examples, to produce a rock as aluminous as the Porphyritic Central Type of Mull (Bailey and others 1924, analyses p. 24, petrography p. 148). Nor are the olivine phenocrysts noticeably less abundant than in the Hebridean or Plateau type, as they are in Mull; for example the feldspar-phyric basalt exposed in The Storr (37902) contains 15 per cent by weight of olivine, and 15 per cent labradorite phenocrysts. It is nevertheless interesting to notice that an occasional Mull example shows porphyritic augite, as seen in 32932.

PETROGRAPHY OF MUGEARITE

In the field the mugearites are fine-grained, dark grey or black trappides, usually showing closely-spaced platy jointing parallel to the bedding. Weathering gives rise to an orange or brown-coloured crust a few mm thick. In this section we are concerned with the non-feldspar-phyric type, which occurs at the summit of the Beinn Edra, Ramascaig and Beinn Totaig groups, and which forms an important element in the Bracadale and Osdale groups (p. 81).

The type-locality for mugearite, Druim na Criche, lies within the Portree (80) Sheet, on the S.W. side of the headwaters of the Glenmore River, 1½ miles due S. of the crofter hamlet of Mugeary. Harker (1904, p. 246 *et. seq.*) defined the rock as follows:

'a dark, finely-crystalline rock, without phenocrysts . . . the exposed outcrops with their yellowish-brown tint and highly fissile character look . . . like trachyte . . . chemical analysis shows, . . . as compared with average rocks of like silica percentage . . . low magnesia and lime and high alkalis, including potash as well as soda . . . rather (a) high amount of phosphoric acid. The chief mineralogical peculiarities . . . which result from its peculiar chemical composition and go to characterise it as a special rock-type are two:
Firstly, the feldspar is not labradorite but oligoclase, with subordinate orthoclase; and, secondly, the ordinary bisilicate minerals are very poorly represented, augite being typically quite subordinate to olivine . . . and iron ore. Among minor points . . . may be noted the unusual richness in apatite.'

The type rock (8732; analysis 'K', Table VIII) forms the lower part of what Harker regarded as a composite sill; but Kennedy (1931) has given strong reasons, including the presence of a slaggy layer at the base of the mugearite, for regarding the Druim na Criche occurrence as extrusive. The upper part of the composite flow, as it is now considered to be, is discussed below, for it consists of big-feldspar mugearite.

Reviews of the application of the term mugearite have been written by A. G. MacGregor (1928), A. K. Wells (1954) and F. Walker (1952). According to the latter's re-definition, mugearite is

'a fine-grained aphyric or microphyric rock rich in oligoclase, fissile, and brightly coloured on outcrop, and with well-marked trachytic feldspar laths . . . less abundant major constituents are orthoclase, olivine and iron ore. Augite is subordinate in amount, biotite and brown hornblende generally present and apatite an abundant accessory. The general aspect is trachytic.'

The recent investigations of I. D. Muir and C. E. Tilley (1961) have provided the important information that the feldspar in the mugearites is potash oligoclase and lime anorthoclase; orthoclase *sensu stricto* is not present. Further, their studies and the present work have shown that the olivine is decidedly richer in the fayalite molecule than is the case in the normal basalts. It is suggested that both features, which are characteristic of the mineralogy of these rocks, could with advantage be incorporated in a modern definition.

Mugearite lavas, besides forming a capping on the great lava escarpment of The Storr, Hartaval and Beinn Edra, are exposed in numerous places in the country between Mugeary and Edinbain. At many points slaggy tops and bottoms can be seen. Boles have been developed on mugearites at The Storr, and at Bealach Hartaval; at the latter locality 160 ft of massive mugearite, with closely-spaced vertical joints, rests on bole overlying a Vaternish type basalt (38099) and is overlain by 20 ft of amygdaloidal mugearite capped by a well-developed red bole (39101). There is no doubt as to the extrusive nature of these rocks.

Olivine forms microphenocrysts generally not over 0·7 mm in diameter, rounded in form, and in some cases showing some intergrowth with feldspar. Measurements of refractive indices show a range in composition in rocks assigned to this group from Fa_{32} (Storr; 37922) to Fa_{60} (Bracadale; 37938). According to Muir and Tilley (1961, p. 195) the olivine in the type mugearite of Druim na Criche shows a range of composition from Fa_{37} to Fa_{58}; in a mugearite-basalt from the Rha River it is Fa_{40-51}, while in a rock from Totardor which is transitional between the mugearites and the trachytes, the advancing iron-enrichment is shown by olivine compositions of Fa_{66-71}: Zoning is plainly seen when a section with an emergent optic axis is examined. In the mugearite from Hartaval analysed for the present account, the olivine in a bromoform concentrate varied little from Fa_{46} and the mineral forms 5 per cent by weight of the rock. In The Storr mugearite (37922) it amounts to no more than 2 per cent, but in other mugearites olivine is more abundant; in the type rock (8732; 39015) it is over 10 per cent.

Alkali-feldspar, previously assumed to be a mixture of oligoclase and orthoclase (though the latter mineral could not satisfactorily be distinguished under the microscope) has now been shown by Muir and Tilley (1961) to be potash oligoclase, showing albite twinning, which grades outward into apparently untwinned anorthoclase. From the Druim na Criche rock they separated three fractions which proved to have the following respective compositions: $Or_{14}Ab_{65}An_{21}$; $Or_{20}Ab_{67}An_{13}$; $Or_{25}Ab_{64}An_{11}$. The characteristic fluxion texture is formed of a mass of subparallel elongate crystals of these feldspars, varying up to about 0·25 mm long. Occasionally a few scattered phenocrysts are present, and these tend to be more calcic than the groundmass; for example, those in the Hartaval rock approximate to An_{50}. It is interesting to note that Muir and Tilley (1961, p. 198) find that the central portions of the plagioclase phenocrysts approach as closely to the high structural state as does any natural occurring plagioclase.

Clinopyroxene can be distinguished in many mugearites, though not in all (e.g. 31397). When present it occurs in small granules, generally yellowish-brown (31391, 31396, 31436) but occasionally purple (32487). Ophitic augite, though not typical, has been noted in a number of instances (31750, 32496, 32925). A microlithic habit is also occasionally seen (34176). Analyses of separated pyroxenes from the Druim na Criche and Rha River rocks published by Muir and Tilley (1961, p. 196) show that these are calcic augites, not greatly different from those normally found in the alkali olivine-basalts; but in the Totardor

TABLE VIII

ANALYSES OF MUGEARITES AND TRACHYTE

Analysis	J	X	K	L	XI
SiO_2	47·51	48·12	49·68	58·64	66·13
Al_2O_3	16·99	16·30	16·99	16·38	16·03
Fe_2O_3	3·31	4·90	3·45	3·05	3·17
FeO	10·60	9·11	8·99	4·91	0·70
MgO	4·23	3·80	2·79	1·06	0·84
CaO	6·48	5·97	5·46	2·90	1·45
Na_2O	5·01	5·69	5·78	6·07	5·34
K_2O	0·70	0·74	1·90	3·49	4·82
H_2O+	1·24	1·01	1·77	0·55	0·36
H_2O-	0·55	0·77	0·34	0·99	0·43
TiO_2	2·85	2·74	2·13	0·89	0·61
P_2O_5	0·53	0·56	0·48	0·66	0·08
MnO	0·20	0·20	0·27	0·18	0·10
CO_2	—	—	—	—	—
F	—	—	0·23	—	—
S	—	tr	—	—	—
Cr_2O_3	—	tr	—	—	—
NiO	—	tr	—	—	—
BaO	—	0·02	0·12	0·13	—
SrO	—	0·05*	—	—	—
Cl	—	—	0·02	—	—
	100·20	99·98	100·40	99·90	99·77

* spectrographical determination.

		J		X		K		L		XI	
Specific Gravity											
Norm											
Q		—		—		—		2·16		12·12	
or		3·89		3·89		11·12		20·94		28·73	
ab		38·25		42·97		38·90		51·35		45·06	
an		21·96		17·24		14·46		6·95		5·28	
ne		2·27		2·56		5·61		—		—	
di	wo	2·90	5·76	3·71	7·33	3·25	7·53	1·39	2·85	0·12	0·22
	en	1·35		1·90		1·30		0·40		0·09	
	fs	1·51		1·72		1·98		1·06		0·01	
hy	en	—		—		—		2·20	6·56	2·01	2·26
	of	—		—		—		4·36		0·25	
Ol	fo	6·47	14·88	5·32	10·52	3·99	10·67	—		—	
	fa	8·41		5·20		6·68		—		—	
ac		—		—		—		—		3·20	
mt		4·87		7·10		4·98		4·41		1·37	
il		5·32		5·17		4·10		1·67		0·67	
ap		1·34		1·34		1·34		1·68		—	
fl		—		—		0·35		—		—	

		J	X	K	L	XI
Normative	or	6	6	18	27	37
	ab	60	67	60	64	57
feldspar	an	34	27	22	9	6

mugearite-trachyte, the composition has entered the ferroaugite field. Nevertheless, iron-enrichment is not as striking (on present evidence) in the clinoporoxenes as in the olivines of the mugearites.

Titanomagnetite is very abundant, considerably more so than in any of the basalts; indeed the abundance of opaque granules is one of the most striking features of the group. Often they are no more than 0·01 mm diameter, but occasionally they range up to 0·1 mm. A polished section of the analysed rock (37876) reveals complete homogeneity in the silver-grey granules, all of which appear perfectly isotropic. The ore fraction separated from the Druim na Criche rock proved to have the composition: magnetite 37·5, ulvospinel 42·8, ilmenite 19·7 (Muir and Tilley 1961, p. 197) as at Hartaval in homogeneous solid solution. The opaque granules are appreciably magnetic.

Apatite can be distinguished in many slices. Zeolites and chlorite occur in small vesicles and chloritic alteration of the olivine is common. To account for the undersaturated C.I.P.W. norm obtained by recalculation of the analysis of the Hartaval mugearite it must be supposed that zeolites are present, though they are not seen in the slices (39100, 37976).

Composition of Mugearite. Harker's description of the type mugearite of Druim na Criche, near Mugeary, was accompanied by an analysis by W. Pollard (Harker 1904, p. 263) which showed 1·47 per cent P_2O_5 (8732). A new analysis by J. H. Scoon of a rock from the same locality, though unfortunately not of a duplicate of the same rock, is recorded by Muir and Tilley (1961, Table 4, column 1). The two rocks appear identical under the microscope, but there are major differences in the estimates, not only of P_2O_5, but also of Al_2O_3, Fe_2O_3 and FeO. For this reason, the older analysis is not reproduced here. In Table VIII, a new analysis of mugearite from Hartaval is compared with the results for Druim na Criche, Rha River and Totardor cited by Muir and Tilley. Compared with the Hebridean basalts, all these rocks are much richer in alkalis, and somewhat poorer in lime and magnesia, as would be expected from their mineralogy. The River Rha rock may be regarded as intermediate between olivine-basalt and mugearite. A number of similar basalts are represented in the Geological Survey collection, their principal characteristics being the presence of feldspar less calcic than labradorite, and the presence of olivine richer in fayalite than in the normal basalts (37899, 37921, 37940, 37993). Transition from mugearite towards trachyte is illustrated by the Totardor rock (37938)[1].

KEY TO TABLE VIII

J. Mugearite-basalt, Rha River above Uig, Skye. Analyst: J. H. Scoon *in* I. D. Muir and C. E. Tilley (1961, pp. 190-1).

X. Mugearite, top of eastern main scarp, Bealach Hartaval, Skye; from hard centre of a flow 180 ft thick. Analysts: W. F. Waters and K. L. H. Murray, Geological Survey Lab. No. 1580 (1951). *Sum. Prog. Geol. Surv.* for 1951 (1953), p. 63.

K. Mugearite from the type locality. Analyst: J. H. Scoon *in* Muir and Tilley (1961) pp. 190-1.

L. Mugearite-trachyte, Totardor, Skye. Analyst: J. H. Scoon *in* Muir and Tilley (1961, pp. 190-1).

XI. Trachyte, Ros a'Mheallain 1½ miles N.E. of Bracadale, Skye. Analyst: J. H. Scoon (1949); analysis communicated by Professor C. E. Tilley.

---

[1] Tilley and Muir have recently proposed the name benmoreite for this rock; *Geol. Fören: Stockholm Forhand,* 1964, **85**, 439.

Owing to the fine grain-size of the mugearites, micrometric analysis fails to yield satisfactory results. It may, however, be of some interest to mention that titanomagnetite reaches as much as 16 per cent by volume in some of these rocks.

PETROGRAPHY OF BIG-FELDSPAR MUGEARITE AND MUGEARITE-BASALT

The mugearite and mugearite-basalt are striking in appearance, with glassy yellowish or white plagioclase in a dense, dark grey groundmass. The upper part of the composite sheet at Druim na Criche was described by Harker (1904 p. 262) as porphyritic olivine-dolerite, with medium labradorites up to one-inch long in a fine-grained groundmass containing feldspar, olivine, augite, magnetite and apatite. The groundmass feldspar, on the basis of extinction angles, was identified as labradorite in this rock, but in a similar rock from Talisker was stated to contain more acid feldspar. Harker moreover noted the unusual richness of the rock in alkalis, and Kennedy (1931) subsequently showed that if allowances are made for the phenocrysts, the groundmass of the Druim na Criche upper member differs very little in chemical composition from the associated mugearite. Wager (1956) has suggested that if 50 per cent labradorite is added to the Druim na Criche mugearite analysis, the resulting composition is near that of the big feldspar rock as regards albite and "iron" ratios. The relevant analyses are reproduced in Table IX.

Additional material has been collected from Druim na Criche and also from Roineval, another locality mentioned by Harker in connection with composite porphyritic dolerite–mugearite sheets. The Druim na Criche rock (33016) has phenocrysts of labradorite near An_{60}, as stated by Harker; they are almost lacking in zoning. The groundmass feldspar certainly also contains some labradorite but zoning to andesine or even oligoclase is present. The other constituents are pseudomorphs after olivine in a green mineraloid, subophitic clots of grey augite, titanomagnetite of about 0·1 mm and some chlorite. With feldspars reaching 0·4 mm., the texture of the groundmass here is appreciably coarser than that of the underlying mugearite (38015) where the feldspars do not exceed 0·2 mm long.

In the Roineval rock (37943-4) the phenocrysts again reach as much as 2·5 cm in width, but here the composition is An_{55}, and the phenocrysts are surrounded by a thin outer zone of oligoclase. There is a marked contrast in this rock between the bulk composition of the phenocrysts and that of the groundmass feldspar, which consists of fluxion oligoclase of composition near An_{20} probably with anorthoclase. Small broken and altered olivines, tiny augite granules and abundant titanomagnetite granules again complete the assemblage, with the addition (37944) of a little brown hornblende. This rock is properly classified as a porphyritic mugearite, and it is clear that the Druim na Criche rock is a porphyritic mugearite-basalt, not a dolerite.

The big-feldspar rocks form conspicuous parts of the lava succession in the country from Mugeary through Edinbain to Beinn Bhreac, and all the remaining 21 sliced examples prove to have mugearite groundmasses. At Ros a'Mheallain, the hill is capped by big-feldspar mugearite which rests, not on mugearite, but on slaggy trachyte (37936). Evidently the big-feldspar rock occurs independently of the composite flows. The rock here (37937) carries labradorite phenocrysts with cores of bytownite, An_{74}, in a groundmass largely of oligoclase, with olivine, subophitic augite and titanomagnetite. Similar contrasts in composition between phenocrysts and groundmass feldspar are shown in other sliced rocks (31283, 31395, 31960, 32502, 32504, 33871, 36224) though cores more calcic than labradorite in the phenocrysts are relatively uncommon (36232-4). All the evidence points to the incorporation of xenocrysts of plagioclase in magma of mugearite composition as the chief factor in producing these striking rocks.

The presence of slaggy tops on rocks of this group (e.g. 38044) leaves no doubt as to their extrusive origin. In the example cited, the phenocrysts have been severely attacked by analcime.

Composition of Big-feldspar Mugearites. No new analysis has been made, but the analysis from Druim na Criche is reproduced from Harker in Table IX. If it is compared with the underlying non-porphyritic mugearite (Table VIII, K) and with the 'Porphyritic Central' type of Mull (Bailey and others 1924, p. 22) this brings out the significantly higher alkali percentages in the mugearitic rocks. A recalculation of the Druim na Criche analysis, subtracting 33 per cent labradorite of composition An_{60} is given; although this corresponds roughly with the amount of phenocrysts present, the result suggests that the groundmass of this

TABLE IX

Analysis of Porphyritic Mugearite

	M	MK	MD	PC
SiO_2	50·33	49·26	48·5	50
Al_2O_3	19·97	21·42	15·2	18
Fe_2O_3	2·81	4·06	4·2	9
FeO	6·23	4·78	9·4	
MgO	3·24	2·02	4·8	5
CaO	8·03	8·60	6·0	10
Na_2O	4·30	4·40	4·1	2·5
K_2O	1·19	1·40	1·8	0·4
H_2O+	0·99	1·07	1·5	
H_2O-	0·87	0·72	1·3	
TiO_2	1·81	1·22	2·7	
P_2O_5	0·17	0·98	0·3	
MnO	0·17	0·19	0·2	
BaO	0·06	—		
S	nt. fd.			
	100·17			

M. " Porphyritic olivine-dolerite ", Druim na Criche, 5 miles S.S.W. of Portree, Skye; Analyst: W. Pollard (Harker 1904, p. 263).

MK. Calculated composition of a rock consisting of one-third labradorite ($Ab_2 An_3$) phenocrysts in a groundmass of mugearitic composition (Kennedy 1931, p. 177).

MD. Composition of porphyritic rock of M with one third labradorite of composition An_{60} subtracted.

PC. Porphyritic Central Magma-type of Mull for appropriate silica percentage (Bailey and others 1924, p. 22).

rock is not identical with the underlying mugearite, but has more calcic plagioclase, a fact already established by petrographical examination. Kennedy's (1931) calculation, in which 33 per cent feldspar of composition An_{75} is added to the non-porphyritic mugearite analysis (Table IX, column MK) gives better agreement, but corresponds less well with the observed mineralogy.

PETROGRAPHY OF TRACHYTE

The trachyte lavas, which occur chiefly in the central and southern regions of One-inch Sheet 80, vary in colour from cream to pale grey. Their slaggy tops and bases tend to assume a purple tint. The rocks exposed by the roadside at Ros a'Mheallain, 2 miles N.E. of Bracadale (37868; analysis XI, Table VIII) shows small scattered biotite and feldspar phenocrysts in a stoney groundmass. The biotite, which is pleochroic X yellow $<$ Z deep brown, has $\gamma = 1{\cdot}630$, presumably lies midway between the magnesium and iron ends of this complex series. The feldspar phenocrysts, where unaltered, are apparently of orthoclase, but they have been extensively converted to stilbite, with perceptible inclined extinction, negative $2V = 30°$, $\alpha = 1{\cdot}491$, $\gamma = 1{\cdot}500$, in the Geological Survey specimens. A little chabazite is associated with the stilbite, and some mesolite occurs in cavities. Rounded crystals of a dark green clinopyroxene with high refringence (satisfactory determinations were not obtained) suggest hedenbergite rather than ferroaugite (37934). A nearly colourless acicular amphibole, with $Z \wedge C = 22°$, $\gamma = 1{\cdot}645$ also occurs in small amount. The main constituent of the rock, enclosing all the others so far mentioned, is alkali-feldspar in laths of about 0·1 mm long, arranged in a trachytic texture. These show more or less parallel extinction. The analytical data show that albite-oligoclase, An_{10} is the main constituent but the problem of potassium substitution in the molecule again arises here, for separate albite and orthoclase in the groundmass are not distinguishable. Scattered granules of titanomagnetite are present, but they are far less abundant than in the mugearite or the benmoreite. In types transitional to mugearite the proportion of the opaque constituent increases rapidly, and is accompanied by a darkening of the colour of the rock (32921, 36240, 38046-7).

The slaggy trachyte (37936) seen above the mugearite which rests on the main trachyte at Ros a'Mheallain contains a well-crystallized zeolite of orthorhombic aspect in cavities. This is identified as heulandite; it is optically positive, has high 2V, $\gamma = 1{\cdot}508$; X inclined at 6° to one strong cleavage.

In addition to zeolites, agate occurs as an amygdale filling in the trachytes (38047). The appearance of quartz in the norm at the trachyte end of the series presented in Table VIII shows that an oversaturated condition is finally attained in these rocks. Fluorine continues to be available, for apatite can be identified in some examples (e.g. 31409).

References

Anderson, T. 1851. Description and analysis of gyrolite, a new mineral species. *Phil. Mag.*, (4), **1**, 111-3.

Bailey, E. B., Clough, C. T., Wright, W. B., Richey, J. E. and Wilson, G. V. 1924. Tertiary and post-Tertiary geology of Mull, Loch Aline and Oban. *Mem. Geol. Surv.*

Chayes, F. 1956. *Petrographic Modal Analysis*. New York.

Chevalier, R., Bolfa, J. and Mathieu, S. 1955. Titanomagnetites, et ilmenites ferromagnetiques. *Bull. Soc. Franc. Minér. Crist.* **77**, 307-46, 365-99.

Deer, A. and Wager, L. R. 1939. Olivines from the Skaergaard intrusion, Kangerdlugssuag, East Greenland. *Amer. Min.*, **24**, 18-25.

Dunham, K. C. 1933. Crystal cavities in lavas from the Hawaiian islands. *Amer. Min.*, **18**, 369-85.

Eyles, V. A. 1952. The composition and origin of the Antrim laterites and bauxites. *Mem. Geol. Surv. N. Ireland.*

Geikie, A. 1861. On the chronology of the trap-rocks of Scotland. *Trans. Roy. Soc. Edin.*, **22**, 633-53.

—— 1867. On the Tertiary volcanic rocks of the British Islands. *Proc. Roy. Soc. Edin.*, **6**, 71-5.

—— 1888. The history of volcanic action during the Tertiary period in the British Isles. *Trans. Roy. Soc. Edin.*, **35**, 21-184.

—— 1897. *The Ancient Volcanoes of Great Britain.* Vol. II, London.

Guppy, Eileen M. and Sabine, P.A. 1956. Chemical Analyses of Igneous Rocks, Metamorphic Rocks and Minerals 1931-1954. *Mem. Geol. Surv.*

Harker, A. 1904. The Tertiary igneous rocks of Skye. *Mem. Geol. Surv.*

—— 1908. The geology of the small isles of Inverness-shire. *Mem. Geol. Surv.*

Heddle, M. F. 1882. Some Ill-determined Minerals. *Mineral. Mag.*, **5**, 26.

—— 1883. A new Mineral Locality. *Mineral. Mag.*, **5**, 117.

—— 1901. *The Mineralogy of Scotland* (posthumous: ed. J. G. Goodchild) vol. II, Edinburgh.

Hess, H. H. 1949. Chemical composition and optical properties of common clinopyroxenes. *Amer. Min.*, **34**, 621-66.

Johnston, R. 1953. The olivines of the Garbh Eilean Sill, Shiant Isles. *Geol. Mag.*, **90**, 161-71.

Judd, J. W. 1886. On the gabbros, dolerites and basalts, of Tertiary age, in Scotland and Ireland. *Quart. J. Geol. Soc.*, **42**, 49-97.

—— 1889. The Tertiary volcanoes of the Western Isles of Scotland. *Quart. J. Geol. Soc.*, **45**, 187-218.

—— and Cole, G. A. J. 1883. On the basalt-glass (tachylyte) of the Western Isles of Scotland. *Quart. J. Geol. Soc.*, **39**, 444-64.

Kennedy, W. Q. 1931. On Composite Lava Flows. *Geol. Mag.*, **68**, 166-81.

Khan, M. A. 1960. The remanent magnetization of the basic Tertiary igneous rocks of Skye, Inverness-shire. *Geophys. J. Roy. Astronom. Soc.*, **3**, 45-62.

King, B. C. 1953. Structure and igneous activity in the Creag Strollamus area of Skye. *Trans Roy. Soc. Edin.*, **62**, 358-401.

Lacroix, A. 1928. Les pegmatitoides des roches volcaniques a facies basaltique. *C.R. Acad. Sci.*, Paris, 321-6.

Macculloch, J. 1816. A sketch of the mineralogy of Skye. *Trans. Geol. Soc.*, **3**, 1-111.

—— 1817. Corrections and additions to the Sketch of the mineralogy of Skye, published in the third volume of the transactions of the Geological Society. *Trans. Geol. Soc.*, **4**, 156-92.

—— 1819. *A description of the Western Islands of Scotland, including the Isle of Man.* London.

MacGregor, A. G. 1928. The classification of Scottish Carboniferous Olivine-Basalts and Mugearites. *Trans. Geol. Soc. Glasgow.*, **5**, 345-9.

MUIR, I. D. and TILLEY, C. E. 1961. Mugearites and their place in alkali, igneous rock series. *J. Geol.*, **69**, 186-203.

PATTERSON, E. M. 1955A. The Tertiary lava succession in the northern part of the Antrim Plateau. *Proc. Roy. Irish Acad.*, **57**, 79-122.

—— 1955B. The Tertiary volcanic succession in the western part of the Antrim Plateau. *Proc. Roy. Irish Acad.*, **57**, 155-75.

PEACOCK, M. A. 1926. The Basic Tuffs *in* The Petrology of Iceland. *Trans. Roy. Soc. Edin.*, **55**, 51-76.

—— 1930. The distinction between chlorophaeite and palagonite. *Geol. Mag.*, **67**, 170-8.

—— and FULLER, R. E. 1928. Chlorophaeite, sideromelane and palagonite from the Columbia River Plateau. *Amer. Mineral.* **13**, 360-82.

RICHEY, J. E. 1948. The Tertiary Volcanic Districts. 2nd edit. *British Regional Geology: Scotland.*

—— and THOMAS, H. H. 1930. The geology of Ardnamurchan, North-west Mull and Coll. *Mem. Geol. Surv.*

STEINER, A. 1955. Wairakite, the calcium analogue of analcime, a new zeolite mineral. *Mineral. Mag.*, **30**, 691-8.

SWEET, JESSIE M. 1959. Uigite from Skye. *Mineral Mag.*, **32**, 340-2.

—— 1960. What is plinthite? *Mineral. Mag.*, **32**. 455-6.

—— 1961. Tacharanite and other hydrated calcium silicates from Portree, Isle of Skye. *Mineral. Mag.*, **32**, 745-53.

THOMSON, T. 1836. *Outlines of Mineralogy, Geology and Mineral Analysis.*

TILLEY, C. E. and MUIR, I. D. 1962. The Hebridean Plateau Magma-Type. *Trans. Edin. Geol. Soc.*, **19**, 208-15.

TOMKEIEFF, S. I. 1934. Differentiation in basalt lava, Island Magee, Co. Antrim. *Geol. Mag.*, **71**, 501-12.

—— 1939. Zoned olivines and their petrogenetic significance. *Mineral. Mag.*, **25**, 229-51.

—— 1940. The basalt lavas of the Giant's Causeway district of North Ireland. *Bull. Volc.* **2-6**, 89-135.

—— 1948. The term " magma-type ". *Geol. Mag.*, **86**, 130.

VINCENT, E. A. 1950. The chemical composition and physical properties of the residual glass of the Kap Daussy tholeiite dike, east Greenland. *Mineral. Mag.*, **29**, 46-62.

WAGER, L. R. 1956. A chemical definition of fractionation stages as a basis for comparison of Hawaiian, Hebridean and other basic lavas. *Geochim. et Cosmochim. Acta.*, **9**, 217-48.

—— STEWART, F. H. and KENNEDY, W. Q. 1948. Skye and Morar. Guide to excursion C14, *XVIII Int. Geol. Cong.*

WALKER, F. 1952. Mugearites and oligoclase-basalts. *Geol. Mag.*, **89**, 337-45.

WELLS, A. K. 1954. Mugearites and oligoclase-basalts. *Geol. Mag.*, **5**, 14-6.

WILSON, G. V. 1935. In *Sum. Prog. Geol. Surv.* for 1934, 70-71

—— 1936. In *Sum. Prog. Geol. Surv.* for 1935, 81-4.

—— 1937. In *Sum. Prog. Geol. Surv.* for 1936, 77-9.

WINCHELL, A. N. and WINCHELL, H. 1951. *Elements of Optical Mineralogy*, Part II. 4th Ed. New York.

Chapter VIII

INTRUSIVE IGNEOUS ROCKS

Tertiary Sills

At some date later than the extrusion of the Tertiary lavas and prior to most of subsequent faulting and dyke intrusions the Jurassic substratum was injected by basic sills on a very large scale. These intrusive sheets do not, as Harker believed, penetrate the lava pile except rarely and then only on a small scale. Although commonly referred to in the plural, these numerous sills appear to be in almost every case the leaves of a single major sill complex within which are more or less isolated rafts of Jurassic sediments.

Prior to the late-Tertiary tilting of the whole region to the west the general level of this sill complex must have been more or less uniformly horizontal and not far above present sea-level.

Now, the sill crops out in the east almost entirely above sea-level and is magnificently exposed in the sea-cliffs extending from Loch Sligachan in the south to Staffin Bay in the north. From thence round the northern end of Trotternish much of the sill is submerged and is responsible for the formation of islands close off-shore. In the west the sill is almost entirely below sea-level except where brought up by local faulting and folding to form islands and promontories such as Isay and Mingay Islands, Ardmore Point, and Eist.

Probably the most remarkable aspect of this sill complex is that although it was intruded into Jurassic sediments which had been already folded into a pitching syncline, nevertheless it appears to have maintained a more or less constant level with regard to the peneplaned surface on which the lavas had been extruded. In order to maintain this level the leaves of the complex, which, in common with most intrusions of this type, had followed the planes of least resistance, i.e. the sedimentary bedding planes, had perforce to transgress the stratification at frequent intervals. These transgressions form one of the most common and spectacular features of the sill complex wherever it is seen, and many other such transgressions can be inferred from the recognizable displacements of the Jurassic sequence.

It is believed that at the time of the intrusion of the sill-complex the lava field had attained a more or less uniform thickness over the whole area and had not yet been dissected by erosion, and that the sill-complex was everywhere injected along a plane of equal pressures. In other words the sill-complex was injected at the level where the magma pressure was cancelled exactly by the overlying rock pressures.

The numerous transgressions of the component sills attracted the attention of Macculloch over a century ago and were somewhat fancifully illustrated in his 'Description of the Western Isles of Scotland' (Macculloch 1819, vol. 3, pl. 17).

Another striking feature of this sill-complex is its uniform thickness. The aggregate thickness of the component sheets visible in any one place appear to be always of the order of 750 ft. This may be an underestimate since it is impossible to be certain that the entire complex is exposed in any one place. Individual sheets may attain a thickness of over 300 ft as for example that which forms the sea-cliff at Meall Tuath, north of Duntulm, but there is great variation. There is some evidence to suggest that this sill-complex is composite. In general the rock is an olivine-dolerite but to the north of the Trotternish peninsula, in particular, picritic and teschenitic variations are found and there is in one or two places evidence suggesting that the rock was not always intruded in the same direction.

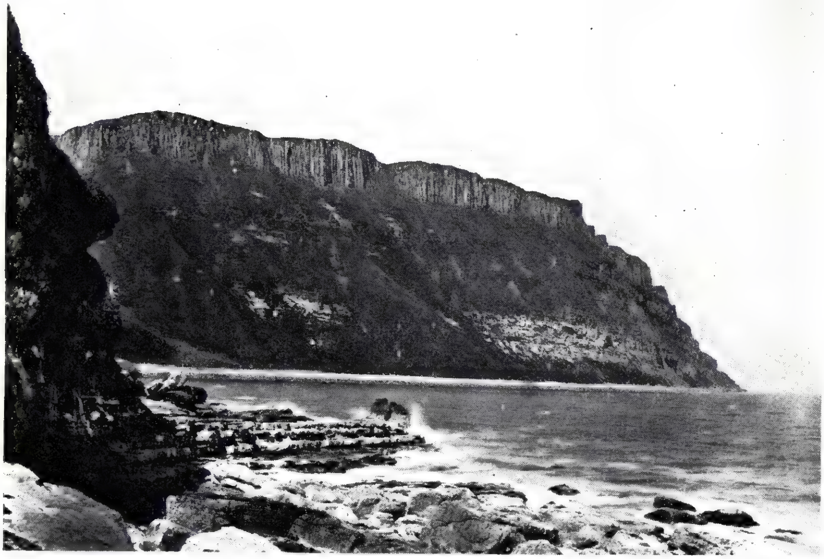
All the thicker sheets display well-developed columnar jointing as is well seen at the Kilt Rock where the columns extend for over 100 ft without a break, and in the cliff section between An Corran and Rubha Garbhaig at Meall Tuath where they attain a length of at least 150 ft. Generally the columns are nearly vertical and normal to the bedding planes of the sedimentary rocks within which the intrusive sheets lie, but in a few cases they are appreciably tilted as at Creag na h-Eiginn north of Flodigarry and on the islands of Trodday and Fladdachuain where the columns lean to the west at angles of 15-20°. At Steall a'Ghreip, one mile north of Flodigarry, the columns are vertical in the lower part of the cliff but bend over toward the west in the upper part. Anomalous jointing is very well displayed in the cliffs east of Rubha Hunish, the most spectacular example being fan-jointing seen in Lub a'Sgiathain which owing to its fancied resemblance to a bird's wing has given the bay its name (Bay of the Wing).

It seems probable that these sudden changes in orientation of the columnar jointing are due to the presence of pre-existing faults or planes of weakness in the country rock which have locally disturbed the distribution of pressures.

Though the major part of the sill-complex consists of olivine-dolerite there are many local variations. Some of these have been studied by Walker (1932), who claimed that he had found evidence of gravity differentiation within certain leaves of the complex. According to Walker four distinct rock types are to be found in the sills, i.e. olivine-dolerite, picrite, dolerite-pegmatite and teschenite. Picrite and picritic-dolerite is said to be found in all the thicker sheets along the coast from Flodigarry to the cliffs west of Camas Mor, and analyses are given of specimens from the cliffs west of Camas Mor and from Kilmaluag.

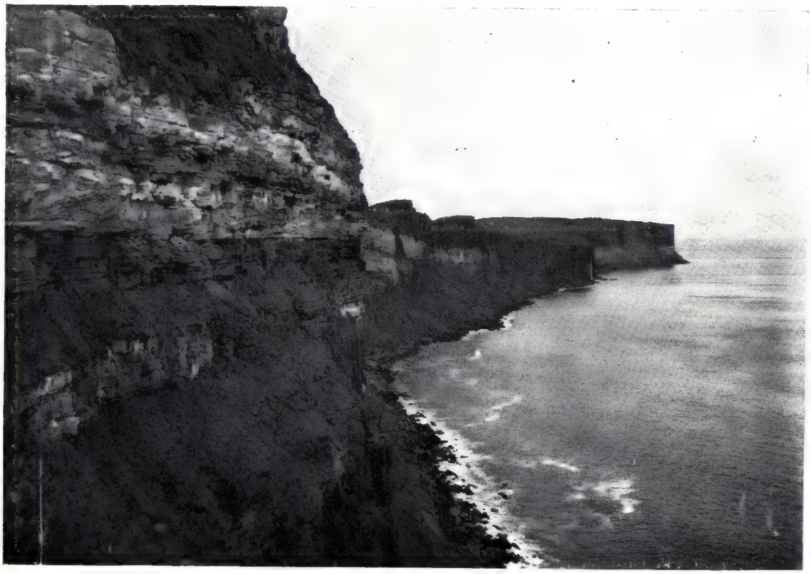
The mapping of the one-inch Rubha Hunish (90) Sheet has confirmed the occurrence of picritic-dolerite at Curidh nan Ob, Duntulm, Kilbride Point, Rubha Hunish, Druim na Slochd, Kilmaluag and Bornaskitaig. The rock Walker referred to as dolerite-pegmatite has been located in the sill at Ru Bornaskitaig, 3 miles south-west of Duntulm, at Rubh'a Chairn Leith, a mile further south, and at Druim na Slochd as well as at the Kilt Rock where it was recorded by Walker but not found by him *in situ*. This coarse-grained rock resembles a gabbro in appearance but differs little in mineral composition from the normal olivine-dolerite of the sill-complex.

A circle drawn on the map centred on the peak of Meall nan Suireamach and of rather less than six miles radius includes all the recorded picritic and gabbroic varieties of the sill. Other minor modifications are seen in that leaf of the sill lying in the Palagonite tuffs north of Fuirnean which is a porphyritic theoleiitic dolerite, and in a small sill seen west of Loch Fada which has crinanitic affinities. By far the commonest variant however, is a teschenitic dolerite, a rock rich in zeolites, which has been found in many localities chiefly lying outside the area of the picritic variants.



(C2244)

A. BEARRERAIG BAY, 6½ MILES NORTH-NORTH-EAST OF PORTREE
Columnar sill of dolerite overlying Inferior Oolite



(C3898)

B. COAST, SOUTH OF MEALT WATERFALL, LOOKING NORTH FROM VALTOS
Great Estuarine Series with intruded sills of dolerite

In the extreme north, the sill forming Eileann Trodday and Sgeir nan Maol is of this type, as is the rock knob of Ben Volovaig, the Ascrib Islands, south-east of Dun Borrafiach, the island of Mingay, south-east of Port na Caigan, the northern end of Beinn Bhreac, the River Chracaig, 2 miles north of Portree, three quarters of a mile south of Loch Fada and a sill in the tuffs south of Loch Fada.

Walker (1932) claimed that gravity differentiation was a feature of these Skye sills. He stated that the only major leaf of the sill which is entirely olivine-dolerite from top to bottom is that over which the outflow of Loch Mealt falls to the sea. This example is however an unfortunate choice for the appearance of this sill is deceptive. What appears to be a sill 190 ft thick is shown by the stratigraphy of the surrounding Jurassic sediments to be in fact the riser of a transgressing sill not more than 30-40 ft thick (see Fig. 7). Thus the vertical face under the Mealt Fall cannot be regarded as giving a vertical section of the sill, and the actual position of the olivine and augite concentration recorded by Walker at 20 ft above the exposed base of the sill cannot be related with certainty to any specific horizon in the sill. The question of gravity differentiation in this sill is therefore still unsettled. Another example quoted by Walker is the sill at Druim na Slochd which is a picrite in the lower part, becomes a picritic dolerite at 80 ft from the base and at 100 ft up is a normal ophitic olivine-dolerite. Unfortunately, this too is a point at which the sill is transgressing from a position near the top of the Great Estuarine Series to a higher horizon in the Corallian and it is impossible to say what are the relative positions in the sill of the samples collected from the cliff face.

In the sill at Meall Tuath, Walker's claim that the lowest visible portion is olivine-dolerite which is succeeded by picrite-dolerite and higher still by dolerite again has been substantiated (p. 126). In the Creagan Iar Sill south of Duntulm the lower two thirds is said to be picrite and the upper third olivine-dolerite. On the other hand in the sill at Bornaskitaig the reverse is said to be the case, picrite forming the upper and olivine-dolerite the lower part of the sill. Thus it appears that there is no consistency in the relationship of the picritic and doleritic portions of the sills in these various localities.

There is little evidence therefore that the picritic phases of the sill are generally due to gravity differentiation *in situ*, though settling may have occurred in certain places. Instead this variation in composition appears to be mainly of a regional character. North of the Uig-Loch Mealt line the sill is generally richer in olivine and includes coarsely crystalline pegmatitic types, south of this line the modifications consist primarily of an enrichment in water and soda.

Harker noted that the sill-complex became thicker northwards and suggested a possible centre of intrusion in the extreme north of Trotternish or in the Shiant Isles. But since he included in his calculations all the hard centres of the lavas above, which he believed to be sills, this argument cannot now be seriously considered. Some grounds can in fact be found for suggesting an exactly opposite origin for the sill. The generalization made earlier in this chapter, that the lava pile was of reasonably uniform thickness, is certainly not true in detail. It seems quite certain, that if the sequence of lavas has been correctly interpreted, there was a gradual thinning of the total thickness in all directions from a centre somewhere in the Bracadale area. It follows therefore that if the sill-complex was intruded from the north the isobaric level should be higher there than in the south. Since this is not the case it appears more likely that the sill-complex originated from more or less the same axis as the lava flows either from a single fissure near the centre of the island or, what is more likely, in view of the regional differentiation of the sills, from the several more or less parallel fissures which give rise to the various groups of flows. There is moreover a grouping of intrusive rock types into areas which show a rough correspondence with those occupied by the lava groups. Thus the picritic dolerite leaves and the sill-complex are found only below the area originally covered by the lavas of the Beinn Edra Group, the rare mugearite sills are found only in the areas occupied by the alternating basalt and mugearite lavas of the Beinn Totaig Group, and the distribution of the acid sills is approximately that of the trachyte and mugearite lavas of the Bracadale Group.

Transgressions of the Sills. In no other part of Britain can the behaviour of a sill-complex be so well studied as in northern Skye both in fine detail and on a broad regional basis. Though there have been innumerable minor transgressions in the various leaves of the sill their aggregate effect is relatively simple.

The highest major sill of the complex is seen at sea-level between Loch Sligachan and Camastianavaig where it occupies a position between the Inferior Oolite and the base of the lavas, sometimes below, sometimes within the Palagonite Tuffs. It is rarely more than thirty feet in thickness. Lower leaves are hidden below sea-level, two of which appear in the sea-cliff just north of Port a'Bhata and transgress the Inferior Oolite until at Craig Ulatota they lie at and near the base of the Great Estuarine Series, only to join, and again transgressing, descend through the sequence to the Middle Lias where they disappear below sea-level except where they form the island of Holm, and further north where these combined sills crop out for a short distance along the shore in Bearreraig Bay. Discrepancies in the levels of the Jurassic sedimentary groups indicate the presence of thick intrusive sheets below the whole of this area, only visible however in the small horst east of Pein a'Chleibh.

The section of the uppermost leaf of the complex seen just north of Fuirnean shows some remarkable features. Here an offshoot from the sill has pushed through the Palagonite Tuffs as far as the basal lava flow which it failed to penetrate (Fig. 3). The transgression forms a series of steps ascending from north to south which have only recently, in the geological sense, been uncovered by erosion so that the steps in the sill form topographic features and the nature of the jointing in each riser is clearly seen. The uppermost step in particular is formed of contorted columns of the type often seen on a smaller scale in the blunt tongue terminating a sill. At Holm this uppermost unit of the sill lies between the Inferior Oolite and the base of the Great Estuarine Series but at Bearreraig it transgresses 260 ft to the north so as to lie in a new position at the top of the White Sandstone of the Great Estuarine Series (Plate III). The average thickness of the upper leaf in this area is about 300 ft.

Half a mile north of Rubha Sughar this uppermost leaf divides into a lower portion which transgresses downwards into the Inferior Oolite and appears to die out at Rigg Burn, and an upper portion which continues at more or less the same stratigraphical level as far as Upper Tote. Just north of Armishader, however, this upper leaf had divided into three and it is the lowest of these which is seen in the sea cliff from Rigg to Upper Tote. The middle limb, at a higher level is only seen in the sea cliff just north of Rigg, whilst the uppermost sheet, occupying a still higher position in the Jurassic sediments forms the great inland outcrop at Creag Langall.

At Eaglais Bhreagach the lowest of these three sheets transgress upwards to a position near the top of the '*Estheria*' Shales. It is faulted down north of Dun Grianan, crosses the Lealt River, where it is responsible for the waterfall just east of the road bridge, and continues at the same stratigraphical level as far as Port Earlish, where a further upward transgression raises the sill 100 ft up into the Concretionary Sandstones.

The middle leaf here reaches the coast again to form the cap of Dun Dearg and rejoins the lower leaf at Loch Mealt. Inland in this area the upper leaf has an outcrop of some 3 miles but this too rejoins the two lower leaves, the line of junction being marked as far north as Staffin Bay by a line of small inclusions of the Ostracod Limestones. North of the Mealt Fall the combined leaves again split leaving a lower sheet at sea-level, forming the lower part of the cliff at the Kilt Rock and the wave cut platform at Sgeir Bhan, and north of the Breun Phort Fault, Sgeir nam Faoileann and Staffin Island. Rubha Garbhaig and An Corran are composed largely of the downfaulted upper leaf.

Though north-south transgressions are clearly visible in the cliff section from Portree to Staffin, east-west changes of stratigraphical level are not so easily demonstrated. At the Mealt Fall the appearance is that of a thick sill which with the exception of a thin band of sediments at the base forms the entire cliff. Two small quarries at the cliff top, however, show that a considerable thickness of the Concretionary Sandstones, the whole of the Lower '*Ostrea*' Beds, and part of the Ostracod Limestones have been apparently replaced by igneous rock. This can only mean that at this point the sill has transgressed upwards for a distance equivalent to the thickness of the missing sediments and that the cliff face is actually formed by the riser of the sill (Fig. 7). In the Maligar, Elishader and Staffin areas the sill complex lies mainly within the Great Estuarine Series. Further north in the area north of and including Duntulm and Kilmaluag and in the west at Peingown, Herbusta and in the area north of Totscore and west of the Hunglader Fault it occupies a similar stratigraphical position.

Further inland the sill transgresses upwards to a position between the Oxford Clay and the Great Estuarine Series. Another lift brings it between the Lower and Middle Corallian. This is a transgression clearly demonstrated by exposures between Flodigarry and Druim na Slochd. In the central area lying almost entirely below landslip and lavas the sill probably occupies a position between the Upper Corallian and the Kimmeridge Clay.

Though the numerous minor transgressions and irregularities of the sill have little effect on the regional distribution of the rocks nevertheless they are important in that they demonstrate the detailed behaviour of a sill-complex of this type and help to resolve certain anomalies of distribution and habit. In the Palagonite Tuffs where bedding is virtually absent the penetrating sill is highly irregular and the columnar jointing contorted as is well seen at Fiurnean (Fig. 3) and Camas Ban (Portree). There are, however, in the Palagonite Tuffs bedded planty flagstones within which the intrusive sheet behaves in a regular fashion. In the closely and evenly bedded sediments of the '*Estheria*' Shales the sills tend to remain at one horizon for long distances but may vary greatly in thickness from place to place without transgression. Changes of level tend to be abrupt and at right angles to the bedding. In the sea cliff north of Rigg Burn a sheet of dolerite having persisted for over a mile with a fairly uniform thickness of 20 ft,

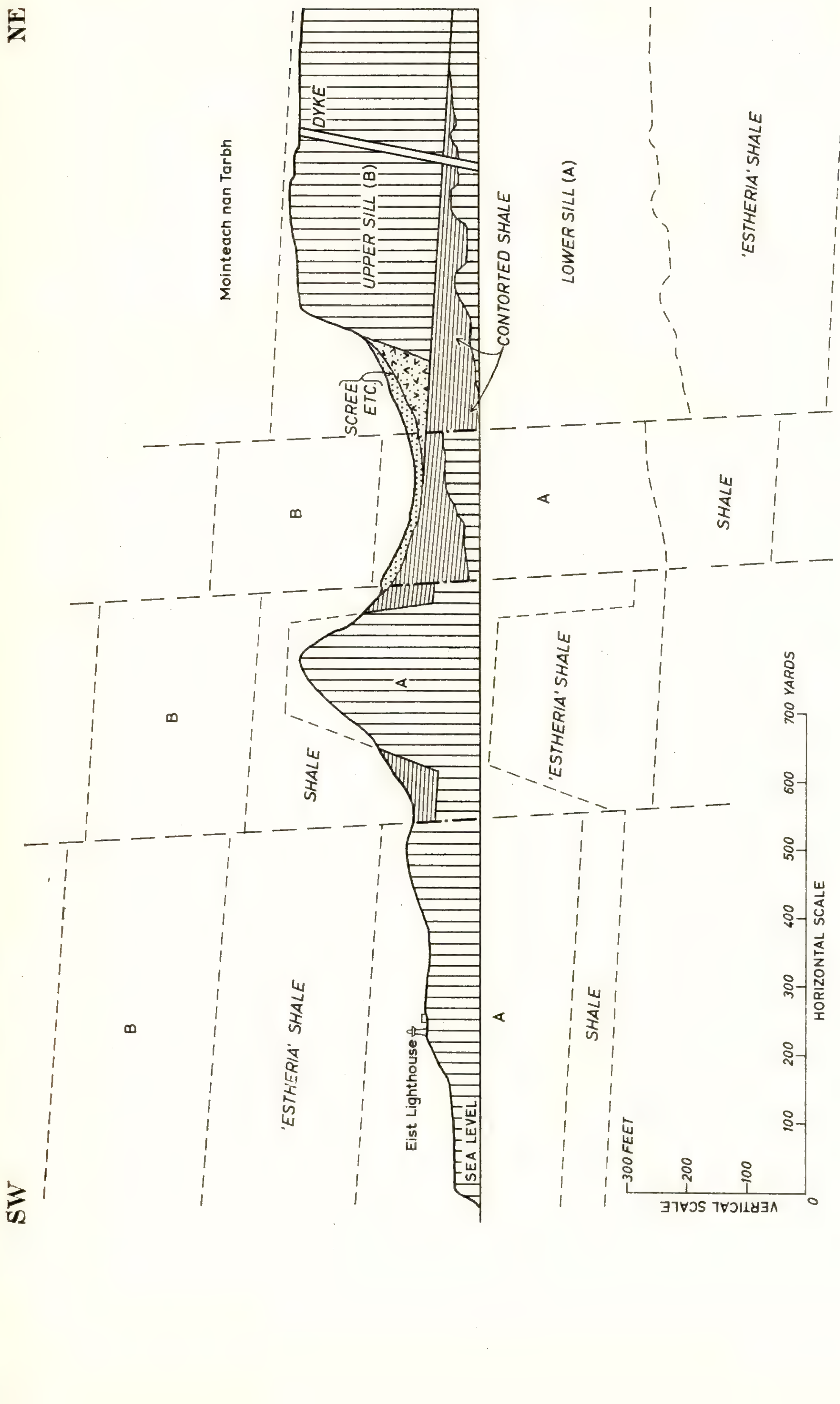


FIG. 14. *Section showing the behaviour of part of the Tertiary sill-complex at Eist*

swells suddenly to 200 ft without transgression. Further north near Rubha nam Brathairean a 20-ft sill in the same position makes eight small vertical transgressions without any change in thickness in a distance of 200 yd.

In the southern face of the gorge below the lower Inver Tote waterfall are exposed three intrusive sheets in the '*Estheria*' Shales. The two lower sheets, 150 ft east of the fall, show an interesting example of mutual interference. The lowest leaf wedges out to the east within a few feet whilst the middle leaf abuts against this termination, retreats, and continues with reduced thickness at a higher level. The shale caught between the opposing sills bears witness to the temperatures and pressures involved. It has been indurated and violently contorted. An even better example of this effect is seen in the '*Estheria*' Shales which form the promontory of Eist and the nearby Mointeach nan Tarbh in the extreme west of Skye. These shales have been invaded by thick sheets of teschenitic dolerite. The lowest leaf has a highly irregular surface, one knob in particular rising 200 ft above the general level of the sill through shales which are highly contorted (Fig. 14). Similar phenomena are visible above this same leaf of sill just before it merges with the overlying sheet which forms Mointeach nan Tarbh in Camas nan Sithean. By analogy with the Lealt River section it seems probable that these irregularities in the lower sill represent attempts at transgression rendered abortive by the presence of the previously emplaced middle leaf above. Also in Camas nan Sithean the Mointeach nan Tarbh sill is seen to give off several vertical risers or dyke-like bodies which in turn have fed numerous thin sills (see Fig. 14). A similar phenomenon is inferred to explain the structure of the sill-complex below Lon Druiseach in the east.

In Oisgill Bay, north of Eist, the lavas are cut by three inclined sheets dipping steeply to the south. The most southerly is thickest and is multiple, the central portion being chilled on both sides against the enclosing sheet. There are a number of irregular offshoots all with chilled margins and in one case with a thin skin of tachylytic glass. In the neighbouring stream draining into Oisgill Bay, '*Estheria*' shales are exposed with leaves of sill above and below. The northern face of this upper sill has the appearance associated with a steeply plunging intrusion, resembling closely the surfaces seen in the irregular transgression near Fiurnean. It is possible that the irregular behaviour of the sills in this area north of Eist is due to the presence of pre-intrusion faults in the Jurassic sediments and perhaps also in the lavas which have determined the course taken by the intruded material.

In the well-bedded sediments comprising the Concretionary Sandstones the sill-complex tends to behave in a more orderly manner though occasionally, and particularly in the sandstones, anomalies do occur. For example in a roadside quarry 2½ miles south of Inver Tote and ¼ mile north of Rigg, two leaves of sill are exposed. The lower shows a transgression of normal type whilst the upper cuts obliquely across the bedding.

In the shales of the Oxford Clay, Corallian and Kimmeridge the sills behave in a similar manner to that described for the '*Estheria*' Shales, i.e. though the sills are in general regular they tend to give rise locally to irregular masses.

There are three features of this sill-complex which are worthy of consideration, firstly its maintenance in general of an isobaric level; secondly the fact that its variations in composition, i.e. olivine-basalt, picritic and teschenite phases are regional in distribution and thirdly the more or less uniform amount of igneous material involved in any one place. With respect to the last it can be stated that in the south the complex consists largely of numerous thin leaves spread through a considerable thickness of sedimentary rock (Fig. 7). Northwards, individual leaves tend to merge or to die out whilst others thicken so that finally in the area north of Loch Mealt the complex virtually consists of two thick sills which at Rubha Hunish are only separated by a thin layer of sediment. The first and third of these considerations suggest that the sill-complex was intruded from a single source and that probably located in the centre of the island in the neighbourhood of the Cuillin igneous masses. The second suggests multiple sources probably from the same fissures that supplied the material for the lava-flows and apparently in the same order.

No mention is made in the above account of the numerous small sills and intrusive sheets which occur as offshoots from the regional dykes. These are all later than the main sill-complex and have no bearing on the problems connected with it.

DYKES

Vertical sheet intrusions or dykes are extremely abundant throughout Skye, so much so that only a selection can be shown on the one-inch geological map. Certain features of their distribution are therefore not evident; for example, the vast majority are olivine-dolerites and it is these that are most frequently omitted from the map, whilst all the rarer rock types are shown. Again there is a marked increase in the size, number and variety of dykes as the Cuillin centre is approached and multiple and compound intrusions become more common. The great majority trend N.N.W., but on the east coast between Portree and Sligachan there are a number of N.N.E. dykes, the predominant direction of the Tertiary dykes on the mainland opposite in Applecross. In the gabbro mass of the Black Cuillins and the area to the west of it are dykes radiating from a centre near the head of Harta Corrie.

Harker (1904, p. 291) devoted an entire chapter of his book to the field relations of the basic dykes. The mapping in N. Skye has repeated many of his observations and confirmed most of his conclusions, but briefly these: i. the basic dykes are remarkably constant in direction which must therefore be primarily due to regional factors. ii. dykes tend to be grouped and are more abundant in some rocks than others. This Harker believed to be due to the degree of penetrability of the country rock, but hardness in itself is not important. Sheet intrusions, whether dykes or sills, appear to follow pre-existing planes of weakness, bedding-planes, joints and faults. Rocks such as conglomerates which do not have any regular planes of weakness offer resistance to intrusion, witness the soft Palagonite Tuffs lying at the base of the lavas in which intrusive sheets become highly irregular and lose direction. iii. many dykes show flow structure, the direction of which is not vertical but inclined at an angle. Clough (*in* Harker 1904, p. 392) recorded the angle of the rodding on the sides of many dykes and they were only rarely vertical. iv. the majority of dykes have a hade to the east, i.e. they lean over to the west in conformation with the general tilt of the region. v. the basic dykes belong to different groups of different ages but there is no certain way of separating them. Their distribution in N. Skye, however, as will be shown in the sequel, could suggest that the majority of the most common group, i.e. olivine-dolerites, belong to the last or regional phase of minor intrusion, whereas those with mugearitic, crinanitic and teschenitic affinities, which are more limited in distribution, appear to be linked with the various lava groups.

In the following account the dykes of N. Skye are dealt with in three groups: 1. trachytic, mugearitic, doleritic, picritic and gabbroic dykes associated with the lava groups, 2. the big gabbro dykes of central area, 3. the regional dolerite dykes, 4. multiple intrusions.

TRACHYTE

Harker (1904, p. 386) referred to a group of trachyte dykes found near the head of Loch Harport as 'The Drynoch Group'. These are of medium width the largest seen crossing Bracadale Burn and being from 15-20 ft across. They vary from light to dark grey in colour and often show a rusty staining connected with the platy fracture. They are non-porphyritic, dull surfaced, fine-grained rocks of low density, consisting essentially of minute feldspar laths orientated parallel to the flow. They are probably, as in the case of the lavas, closely connected with the mugearites, from which they differ chiefly in the absence of olivine.

It is perhaps significant that these trachyte dykes lie entirely within the area occupied by the trachyte lavas. The Broadford and Sleat trachyte dykes studied by Clough (*in* Harker 1904, p. 388) appear not to be directly connected with the former group, They commonly have spherulitic margins and the sides frequently exhibit a "rodded" structure the inclination of which Clough carefully recorded and found that the average was in the neighbourhood of 45° from which it could be assumed that the movement of magma in the dykes was more or less at this angle. Harker thought these to be amongst the latest of the intrusions. Certainly their distribution suggest an origin from the granitic rather than from the gabbro centre whereas the Drynoch group seem to originate from the latter, and to be earlier in time. But the exact age relationship between these trachytes and other dykes has not been discovered in the field.

MUGEARITE

Harker (1904, p. 331) first recognized mugearite (oligoclase-dolerite) as a distinct type of basic dyke and described as the best example that at Am Bile, about 1¼ miles E.N.E. of Portree. This however, is somewhat unusual in having a high proportion of glass and is perhaps better classed with the variolites (Harker 1904, p. 347).

The mugearites differ from the normal basic dykes in having a higher silica percentage, lime, and especially magnesia lower, alkalis (including potash) higher. In the field they are dark with a bluish sheen, finer grained than most dolerites and usually exhibit a platy structure. As in the lavas the mugearite dykes appear both in non-porphyritic and feldspar-phyric form. They are not very common but some are large, for example two cross Vidigill Burn E. of Loch Harport 45 yd apart, one being 75 ft and the other 30 ft or more across. Some twenty of these dykes have been mapped, apart from those forming part of multiple intrusions, of which eight are feldspar-phyric. The most northerly seen are an 8-ft non-porphyritic in Aros Bay, Vaternish, and a 10-ft feldspar-phyric mugearite on the northern slope of Creag Madragil in Trotternish. Their distribution is virtually that of the mugearite lavas, though they are most abundant in the Drynoch area and their orientation is in the regional N.N.W. direction except for one running east-west at the south end of Tarner Island in Loch Bracadale.

The single example of a Leidleite (augite–andesite) dyke which crosses the Tungadal River is probably to be associated with the Drynoch group of mugearite dykes with which it is petrographically closely related.

Also to be associated with the mugearites are the Variolite dykes, i.e. andesitic or mugearitic basalts with interstitial glass and a variolitic texture. Of these the Bile (Beal) dyke has already been mentioned. Others have been seen as follows: in Allt Yelkie, 1 mile east of Cnoc Steud, just south of Uig, 4 ft in width; another 4 ft, cutting the Creag Langall sill about 2 miles south of the Lealt River; and one 8 ft wide, crossing Eas na Coille rather less than ½ mile before it joins the Varragill River. These all lie within the area occupied by the eastern group of mugearite lavas.

DOLERITE

Olivine-dolerite. Dykes of olivine-dolerite are by far the most abundant in N. Skye. It is clear that the majority belong to the latest phase of the vulcanicity for they cut lavas and sills alike and are mostly later than the faulting. In general the trend is the normal, veering between N.W. and N.N.W. but there are deviations, particularly on the east coast in the area between Portree and Sligachan where a number of these dykes have a trend veering between N. and N.E. It cannot be concluded, however, that there is any great difference in age between these two sets since they cut each other indiscriminately as can be well seen on the coast between Holm Island and Bearreraig. A possible explanation of these deviations is that they are due to disturbances in the Tertiary fault pattern by an earlier fracture of some magnitude in the Sound of Raasay (see p. 174).

Essentially these dykes behave in a similar way to the other sheet intrusions the sills, but in the vertical plane. End terminations are rarely observed but one dyke on the W. side of Meall Tuath dies out upwards. Lateral displacement of dykes follows a similar pattern to that described by Clough (*in* Harker 1904, pp. 302-4, figs. 64-67). Typical examples were recorded by Messrs. John Knox and T. R. M. Lawrie during the mapping of N. Skye.

No single olivine-dolerite dyke has been recorded which exceeds in width that in Lon Airigh-uige in Glen Uig i.e. 20 ft. There is one 10 ft wide at Ard Beag in Vaternish but the majority are less than this.

Feldspar-phyric olivine-dolerite dykes are not common; there are two, one 14 ft and the other 20 ft wide 1 mile west of Sgurr a Mhalaidh, and two others one 2 ft-2 ft 6 in and the other 12 ft wide, one mile and two and a half miles south of Uig respectively, all in Trotternish. On the east side of Loch Greshornish several of the dykes of this type occur in groups of four or five. The distribution of these porphyritic dolerite dykes does not appear to have any special significance.

Analcime-dolerites. Dolerite dykes rich in analcime and with an ophitic texture resemble those first described by Flett (*in* Cunningham Craig and others 1911) as Crinanites. Others with more analcime and less olivine approach the teschenites. Both crinanitic and teschenitic dolerite dykes have a similar distribution; there is a small group in the Kilmaluag-Duntulm area all under 6 ft in width, a second group occupies a long narrow oval area running from Meall a Fhuarain N.N.W. to Kilbride Point in Trotternish, and a third group form a similar pattern in the area between Colbost and Dunvegan Head. The axis of these last two areas coincide more or less with the fissures responsible for the Bracadale and Osdale Lava Groups.

The widest crinanitic dyke seen was that in Coire Iomhair, measuring 18 ft, two others were 12 ft, i.e. that just south of Cnoc Steud, south of Uig Bay and that 1/6th mile west of Meanish in Loch Pooltiel, Duirinish. On the coast about ½ mile south-east of Colbost Point in Loch Bracadale is a 5-ft crinanitic dyke unusual in two respects. It is vesicular and runs W.S.W. Feldspar-phyric crinanite dykes are rare. Those seen were all in the west e.g. that ½ mile north of Gob na Hoe, one 12 ft wide ⅙th mile south of Greshornish House and a 5-ft example ⅓ mile due west of Cnoc a'Chrochaire.

Single dolerite dykes with teschenitic affinities are all small, the largest seen being 8 ft wide and situated near the south end of the sediments in An Leth-pheighinn, Hamra River.

In the Allt na Glas Bhuaile is one 6 ft wide but the remainder are 4 ft or less in width. Feldspar-phyric teschenites are rare, only four have been recorded, the largest of which is one 10 ft wide at Ru Chorachan, the southern point of Uig Bay.

PICRITIC DOLERITE

A relatively small number of the dolerite dykes are unusually rich in olivine and augite and so approach picrite in composition. They appear to be related to other dykes recorded as gabbroic dolerites and with these are apparently the latest of this series of minor intrusions, according to the evidence of the multiple dykes (see p. 137).

East of a line drawn north-south through Edinbain the picritic types predominate, west of it the gabbroic dykes are more common. All follow the usual N.N.W. or N.W. direction.

The largest picritic-dolerite dyke seen is 30 ft wide and runs one mile east of Kildonan; S.S.E. of Beinn Tuath is one 12 ft wide, and a 10-ft wide example crosses the River Ollisdal, ½ mile from the coast. One 5 ft wide crosses the River Tora ½ mile south of its junction with Allt Garbh and further north one 9-10 ft wide runs north and east of Glenuachdarach in Hinnisdal, another ½ mile S.E. of Camas Beag, Uig Bay, is 6 ft 6 in wide.

The gabbroic dykes fall into two categories i.e. those which behave as normal dykes and others treated separately, which are better described as igneous 'pods'. The first group, though some are larger than the average, occur as normal dolerite dykes and enter in association with other to form composite intrusions. They are mainly confined to the western half of N. Skye in Duirinish and Vaternish though one, 10 ft wide, crosses Lon Breac about 1 mile east of Lon Ruadh and west of Beinn a' Sga. The largest seen was 50-60 ft wide at the south end of the Ardroag peninsula on the west side of Loch Vatten. Another 20-40 ft wide is to be found 1 mile east of Loch Beag, Bracadale, and east of this, one west of an the other north-east of Meallan Gainmhich. At the head of Loch Dunvegan and ⅙th mile south of Kinloch is one 30 ft wide and in Duirinish is a 10-ft wide gabbro type at Gob na Hoe.

GABBRO AND ALLIVALITE

The big gabbro and allivalite dykes differ in that the plagioclase of the gabbro is labradorite whilst that of allivalite is anorthite. Gabbros, by reduction of their ferric constituents, may grade into the pyroxene-free allivalites, and there is no doubt at all judging by the field relationships that these very large intrusive masses are all very closely related geographically, temporally and petrographically. They occur as a compact group between Bracadale and Beinn a'Chleirich within an oval area about three miles along the N.N.W. axis and two miles along the short axis.

The most southerly is on the west side of Beinn nan Braclaich on the same line as a long allivalite–gabbroic dyke which crosses Loch Beag at Struan. It is about 500 yd long and about 100 yd in width and appears to be a composite or multiple intrusion made up of four leaves of alternating gabbro and allivalite.

Some 400 yd to the N.N.W. along this same line another intrusion of this type crops out on either side the Broisgillmore Burn exhibiting very clearly the peculiar attributes of these 'dykes'. The gabbro-allivalite is emplaced in feldsparphyric mugearite lava and consists of two pods on the same axis but not continuous with one another though only a few yards separate them and the burn which runs between is entirely in mugearite.

The rock is fine grained at the margins and appears to be a crinanitic dolerite but the centre is vesicular and gabbroic.

The walls of the intrusion appear to diverge upwards like the sides of a boat and the ends similarly curve under in a boat-like fashion. It might have been thought that these 'dykes' represent the upper portions of a vent just before it merged into a lava-flow and that the very considerable bulk of the dykes and the nearness of the overlying flow has allowed them to cool sufficiently slowly to crystallize as coarsely as the gabbro of the Cuillin laccolite. The petrographic evidence (p. 170) however, shows that they were intruded as a mush of coarse crystals, lubricated by a small amount of alkali basalt magma.

Rather less than 1000 yd further along the same line to the N.N.W. another of these intrusions crosses Glen Ose about 1 mile north-east of Osdale. This, more than 150 ft wide, is classed as an allivalite. Continuing in the same direction for a little over a mile another, rather larger allivalite dyke is to be found on the east side of An Cleireach. This intrusion is over 1000 yd long and from 150-170 ft wide. Near its southern end a sill of the same rock follows the base of a lava-flow E.N.E. towards Allt Ruairidh, one of the very few sills known in the lava series. The 'dyke' is cut by a later olivine-dolerite dyke 6 ft wide with a N.W. trend.

This line of apparently discontinuous intrusions is almost 5½ miles in length extending from Glas Bheinn in the south to Bheinn a' Chleirich in the north.

Another possible fissure with a slightly more northerly trend lies between 1 mile and 1½ miles to the east. At the northern end on the southern slopes of Cruachan Glen Vic Askill is the largest of these 'dykes' over ¾ mile long, and 300 ft wide; it is classed as an allivalite. At its southern end and 200 yd to the west is another 'pod', this time gabbroic, about 230 yd long by 270 ft wide.

Southwards on the south side of the Ose River and 300 yd N.N.E. of Dun Arkaig is a possibly related gabbroic dyke 300 ft or so wide and about 600 ft long.

On the north side of Am Bidean is another similar gabbroic 'pod' about the same width as the last but considerably shorter. This is not in line with any other than perhaps one of the gabbroic dykes in the Voaker Burn east of Bracadale and seems to have no specific connections with the other 'big' dykes.

These very large gabbro-allivalite intrusions present a problem which would well repay closer investigation. They are not normal dykes. They are earlier than some of the olivine-dolerite, presumably regional, dykes. If they are feeders for lavas then they must be very late in the history of the extruded rocks for they cut the mugearite and basalt flows of the most recent lava series, and could only be related to still later flows no evidence for which now remains, yet their obvious alignment suggests a definite relation to a fissure.

REGIONAL DOLERITE DYKES

It is thought that the majority of the olivine-dolerite dykes belong to the final period of the collapse of the lava field. They are medium-sized intrusions very uniform in type and in all respects similar to the dykes described in Mull as being of the Plateau Basalt type (Bailey and others 1924, p. 368). The majority are less than 20 ft in width but often of considerable length. They appear to be later than almost all the faulting. Non-porphyritic and feldspar-phyric types are equally common. Since it is rarely possible to distinguish the late dolerite dykes from others of earlier date little can be said about their distribution. It seems however, that they tend to increase in size and number towards the Cuillin area.

MULTIPLE INTRUSIONS

Not only are simple olivine-dolerite dykes the most common in N. Skye but they most frequently combine to form multiple intrusions either with each other or with dykes of different composition.

Twelve examples of multiple olivine-dolerite dykes have so far been recorded. Some are fairly large; one just south of Lon Chaorach on the east side of Glen Varragill is over 20 ft wide. Others of this size occur at Knockbreck in Vaternish, and on the south side of Eileen Creagach in the Ascrib Islands. A good example of a triple olivine-dolerite dyke 16 ft wide is to be seen in Geary, Vaternish, and 1/6th mile south of Rubha Glas; in Loch Snizort Beag is a quadruple dyke with leaves 1 ft, 2 ft, 8 ft and 7 ft wide.

On the west side of Rubba nan Cudaigean, also in Loch Snizort Beag, is an unusual type of intrusion consisting of six olivine-dolerite dykes, closely approximated with only thin sheets of basalt lava separating them, in all 30 ft across. Often one of the leaves of these multiple dykes is a crinanitic or teschenitic dolerite. For example, a crinanitic dolerite forms the middle leaf of a triple dyke 12 ft wide in the cliff, ¾ mile north of the southern end of Meall Greepa in Loch Bracadale; and on the east side of Loch Greshornish near Kildonan is a multiple dyke, 55 ft wide, made up of alternating olivine-dolerite and teschenitic dolerite leaves. This dyke actually consists of an 8-ft feldspar-phyric dolerite on the east separated by a 12-in sheet of basalt, from a 47-ft teschenitic dolerite on the west into which has been intruded a later feldspar-phyric dolerite dyke 2 ft thick.

Combinations of olivine-dolerite and mugearite dykes are also found in which the latter appears to be the later intrusion. An interesting example of this was recorded by Mr T. R. M. Lawrie 600 yds W.N.W. of McQueen's Loch in the lavas of Ben Tianavaig. In this 40-ft wide intrusion the central member is a feldspar-porphyric mugearite with variolitic dyke against its east face and flanked on both sides by olivine-dolerite. The order of intrusion determined from the chilling of the margins was: olivine-dolerite, variolite, mugearite. On the other hand in a 20-ft triple dyke on the east side of Port Beag, Loch Harport, olivine-dolerite is the middle member flanked by mugearite, and similarly in the Sumardale River a 3-ft olivine-dolerite dyke is emplaced between an 8-ft and a 4-ft feldspar-phyric mugearite.

In the Tungadal River, about 1 mile south of the mouth of Vidigill Burn Mr. John Knox recorded an unusual combination of dolerite and mugearite intrusions. This is a slightly sinuous dyke exposed for about 200 ft. An 11-ft feldspar-phyric mugearite dyke has been emplaced in the centre of a 6-ft olivine dolerite, whilst four other mugearite sheets have been intruded on the east side of it. Where the mugearite is in contact with itself there appears to have been mutual chilling so that the several leaves were probably not exactly contemporaneous.

Combinations of olivine-dolerite and gabbroic dykes are also found as at Rubha Dubh on the west side of the Vaternish peninsula, but only one case was discovered where the age relationships were clear. At Poll a'Bhaine, Greshornish, a 12-ft gabbroic dyke is emplaced in a coarse olivine-dolerite. A 10-ft fine-grained dolerite dyke alongside the gabbro may be a still later addition.

The crinanitic and teschenitic dolerites also occur as multiple dykes. For example a double crinanitic dyke occurs on the west side of Aird Point, Loch Snizort Beag, and a double teschenitic dyke 4 ft wide on the west side and 8 ft on the east crosses Lon nan Achadhanan, east of Glengrasco. Combinations of crinanitic and teschenitic dykes are rare but one is to be seen in the Treaslane River, north-west of Uigshader and another at Corran at the northern entry to Loch Eyre.

Multiple mugearite dykes are equally rare. A good example is a 20-ft triple intrusion in Lon Salach, ⅔ mile west of Balmeanach, where a non-porphyritic mugearite has been emplaced in the centre of a feldspar-phyric mugearite dyke.

The gabbroic dykes do not often occur as multiple intrusions. In two cases they are known to run alongside crinanitic dolerite dykes i.e. between Meallan Gainmhich and An Leitir, west of Glen Varragil, and again ½ mile south of Rubha Bhreidein in Loch Greshornish. Gabbroic dykes accompanied by olivine-dolerite intrusions have already been mentioned but the association of gabbroic and teschenitic dykes has not been observed in N. Skye.

An interesting multiple dyke is that crossing Lon Loch Mhair on the north side of Glen Hinnisdal. It is 10 ft wide and is made up as follows: mugearite, olivine-dolerite, gabbro, mugearite.

Only one case is known of allivalite as part of a multiple dyke i.e. on the east side of Gairbh-sgeir, at the southern end of Lub Score is a 20-ft intrusion in which an allivalite sheet has been emplaced in the middle of an olivine-dolerite dyke.

AGE RELATIONS OF THE DYKES

Multiple dykes should yield valuable evidence as to the order of emplacement of the various types. Unfortunately, this is not always forthcoming and no firm conclusions can be reached on present evidence. All that has been so far established is that some of the olivine-dolerite dykes are earlier than the crinanitic dolerites, than the mugearitic, and than the gabbroic and allivalite dykes. Other olivine-dolerites are later than the teschenitic dolerites, than the mugearites and than the gabbroic dykes. A possible order of intrusion for the dyke rocks is then: 1. teschenitic dolerite, 2. olivine-dolerite, 3. crinanitic dolerite, 4. olivine-dolerite, 5. mugearite, 6. olivine-dolerite, 7. gabbro and allivalite, 8. olivine-dolerite.

INCLINED SHEETS

Intrusive sheets in the lavas at Biod Ban, Oisgill Bay, which may be either regarded as dykes or sills have already been described (p. 131). Four similar but smaller sheets cross the Vidigill Burn just over a mile S.E. of Ben Duagrich; they are all olivine-dolerite and from the lowest upwards are 30 in, 20 in, 36 in, and 22 in thick.

VENTS AND AGGLOMERATES

In view of the vast outpouring of lavas in the area of N. Skye it is surprising that so few vents have been located. Mr. Knox records a lens of agglomerate 30 yd long by 4 ft thick on the west side of Lyndale Point within which are two dykes showing anomalous behaviour. The agglomerate is a breccia largely of lava but with some bole and a few fragments of baked shale.

In Loch Bracadale a dyke-like strip of agglomerate occurs on the shore at Ullinish and again ¼ mile further north in the same small bay. Agglomerate has also been recorded 350 yd south of Osdale in Glen Ose, and again in Glen Bracadale associated with trachyte lavas, and south of Gesto House, but none of these can be confidently regarded as vents.

It would seem that for the most part explosive eruption was confined to the earliest stage of volcanic activity when the Palagonite Tuffs were being formed. This deposit in many places contains brecciated lava and resembles an agglomerate but nothing representing a true vent has been observed.

REFERENCES

BAILEY, E. B., CLOUGH, C. T., WRIGHT, W. B., RICHEY, J. E. and WILSON, G. V. 1924. Tertiary and Post-Tertiary Geology of Mull, Loch Aline and Oban. *Mem. Geol. Surv.*

CUNNINGHAM CRAIG, E. H., WRIGHT, W. B. and BAILEY, E. B. 1911. The Geology of Colonsay and Oronsay, with part of the Ross of Mull. *Mem. Geol. Surv.*

HARKER, A. 1904. The Tertiary Igneous Rocks of Skye. *Mem. Geol. Surv.*

MACCULLOCH, J. 1819. *A Description of the Western Islands of Scotland including the Isle of Man.* London.

WALKER, F. 1932. Differentiation in the Sills of Northern Trotternish (Skye). *Trans. Roy. Soc. Edin.*, **57**, 241-57.

Chapter IX

THE PETROGRAPHY OF THE MINOR INTRUSIONS

History of Research

The intrusive nature of the numerous basaltic sheets which occur within the Jurassic rocks wherever they are exposed beneath the lava plateau of Skye was first conclusively demonstrated by Macculloch (1819). Geikie (1897, p. 305) remarked that the east coast of the island, especially the stretch from Loch Sligachan to Rubha Hunish 'has been classic ground for this part of volcanic geology since it supplied the materials for Macculloch's descriptions and diagrams'. The sills of Trotternish have nevertheless not received from petrographers the attention that might have beeen expected.

Geikie identified the rocks of the sills as 'somewhat largely crystalline ophitic dolerites, gabbros or diabases' and stated that they exhibit a persistent uniformity of composition and structure characteristic of sills and dykes. He added that the sills probably continue north of Skye beneath the sea, for at least twelve miles, since sills of the same type form the Shiant Isles, where on Garbh Eilean the great northern cliff exhibits a single sheet over 500 ft thick. Judd (1885) visited the Shiant Isles and found that in addition to ophitic dolerite and gabbro, an ultrabasic type which he named dunite was present. Geikie was unable to find this rock *in situ* but remarked that it probably occurs at the base of some of the sills, where it has segregated from the rest of the mass. Notwithstanding his earlier statement, Geikie was impressed with the considerable variety in texture displayed by the Shiant sills (Geikie 1897, p. 309).

Modern petrographical study of the sills may be said to have begun with F. Walker's (1930) investigation of the Shiant Isles and since this and subsequent work offers strong support for Geikie's contention that the system of sills here is, or was, continuous with that of Trotternish, this work is germane to the present account. Walker found, at the base of the Garbh Eilean sill, a layer of picrite with 50-75 per cent olivine, which gives place to dolerite rich in olivine 15 ft above the beach; this in turn is transitional into crinanite at 45 ft above the beach. The sill is evidently an upper leaf of the system, for a lower leaf appears beneath the ledge of Whitbian strata on which it rests. The separation of the picrite was ascribed by Walker to gravitational differentiation by sinking of the olivine crystals. In addition to the picrite-crinanite series, he also recognized pegmatitic and syenitic segregations. Subsequently Walker (1931) investigated the small islands between the Shiants and Trotternish, Fladda-chuain, Gaeilavore, Gearran, An Bord, the three Skerries and Trodday, all of which lie within the area shown on the one-inch Rubha Hunish (90) Sheet. All expose alkali olivine-dolerites and related rocks. Finally he investigated the north Trotternish sills (Walker 1932) demonstrating the existence of picritic types W. of Kilmaluag Bay, at Druim na Slochd, at Creag na-h-Eiginn and in the cliff at Meall Tuath. In all these cases, dolerite overlies picritic dolerite or picrite. Gravitational differentiation was advocated for some of them but intrusion of viscous picrite, crowded with olivine crystals was also envisaged (Walker 1932, p. 252) to account for the exposures W. of Kilmaluag Bay.

Interest in the Shiant sills has been revived by H. I. Drever (1953) and his associates. A new traverse of the difficult face of Garbh Eilean has revealed an abrupt contact between picrite and picrodolerite, defined by a thin layer with very small olivine granules, a little interstitial plagioclase and no clinopyroxene. The picrodolerite passes gradually upwards into crinanite. Detailed studies of the olivines (Johnston, 1953) and of the clinopyroxenes (Murray 1954) from the rocks on this traverse have yielded very interesting results; the olivines develop highly fayalitic outer zones in the upper part of the sill, while a limited upward enrichment in iron is displayed by the pyroxenes.

Harker's (1904) memoir contains descriptions of a few of the dykes within the present area but as the primary survey of the Portree (80) and Rubha Hunish (90) sheets had not been made, his account is necessarily incomplete.

PETROGRAPHY OF THE SILLS

This account is concerned solely with the sills intruded into the Jurassic sediments, except for three inclined sheets exposed in Oisgill Bay, which penetrate the lavas, but which are believed to be connected with the sills exposed nearby in the sediments. As already noted, Harker's 'Great Group of Sills' (Harker 1904, pp. 235-54) are now considered to be the central columnar portions of lavas.

The sills in the Jurassic sediments, although they occupy various stratigraphical horizons from the Middle Lias to the Kimmeridgian, are linked together and were most probably produced by a single pulse of magma, or a series of pulses close together in time, since (except at Oisgill Bay) clear evidence of chilled internal contacts have not been discovered. The variants may well have developed from a single magma, within the spaces now occupied by the sills.

Although the sills with their boldly columnar outcrops present an appearance of uniformity, detailed examination reveals considerable textural and mineralogical variation. The following types will be recognized for purposes of petrographical description: (1) normal olivine-dolerite, (2) marginal tachylitic and basaltic modifications, (3) picrodolerite, (4) crinanitic and teschenitic variants, (5) pegmatic dolerite.

OLIVINE-DOLERITE

The constituent minerals are forsteritic olivine, diopsidic augite, moderately calcic plagioclase, titanomagnetite and very small amounts of zeolites, particularly analcime and thomsonite. The rock in hand-specimen is dark grey, with the grain-size usually just sufficient to reveal to the naked eye that rounded olivines and tabular feldspars are present in a "doleritic" texture. Weathering imparts a dull reddish-brown or dirty grey skin.

The olivine is rounded to subautomorphic but it never shows sharply-developed crystal faces. It ranges from about 0·2 to 2·0 mm in diameter; occasionally a tabular tendency, parallel to (010) can be detected. In thin section it is invariably colourless in all the dolerites investigated. Yellowish-brown fayalitic varieties similar to those in the upper part of the Garbh Eilean sill, which were first noticed by Walker (1930, p. 366); commented on by Tilley in the discussion on this paper, and fully investigated by Johnston (1953), who found that they range up to Fa_{95}, have not been discovered in any of the Trotternish rocks. Refractive index measurements indicate a range of composition from Fa_{18} to Fa_{24}, with some indication of very thin outer zones a little richer in iron orthosilicate. Most olivines enclose one or two tiny magnetite octahedra.

The olivine has nowhere been found to enclose feldspar as at Garbh Eilean (Johnston, 1953); its crystallization here seems to have been completed before that of feldspar began.

The plagioclase is tabular parallel to (010) but shows no preferred orientation. The mesh of thin platy crystals imparts the characteristic doleritic texture to the rock. The maximum length of the feldspar is about 2·0 mm in the coarsest varieties of the normal olivine-dolerite; but the range of sizes is considerable, and not every thin section shows an average length of feldspars over 0·5 mm (the lower limit for dolerite *sensu stricto* adopted here). Albite and Carlsbad seem to be the dominant, though not the only twin laws. The maximum anorthite content recorded here is An_{76} (from refractive index and Albite-Carlsbad extinction measurements; this may be compared with An_{80} in the Shiant Sills). Normal composition zoning without reversals is the rule, and compositions down to An_{32} have been found. The mean feldspar composition cannot be estimated from microscopic observation but the normative figure derived from a chemical analysis (p. 148) is $Or_7Ab_{37}An_{56}$.

No orthopyroxene and no evidence of pigeonitic clinopyroxene (of low 2V) has been found in these rocks. The pyroxene is augite, preserving a characteristic pale biscuit colour in every thin section, and forming xenomorphic crystals commonly up to 4 mm × 2·5 mm, but sometimes exceeding over 10 mm in length. In composition it is a diopsidic augite, and though Murray's analyses of pyroxenes with similar optical properties in the Shiant crinanite showed 1·24 to 1·33 per cent of TiO_2, no distinct purple colour such as is found in the pyroxenes of some alkali olivine-dolerites was noted.

The titanomagnetite is automorphic or hypautomorphic, but it is a later mineral which sometimes had wrapped itself around the feldspars. There is some reason to believe that it may have developed its crystal faces by replacement of adjacent minerals, and the possibility that the opaque octahedra in the olivines are really of later crystallization than the olivines is worthy of consideration. A little apatite occurs.

Zeolites, though occasionally present, are minor constituents only of the normal dolerites. Pale brown or colourless analcime, and fibroradiate thomsonite are sometimes found in interstitial positions.

Excellent examples of the normal dolerites in the Geological Survey collection come from near the Loch Mealt waterfall (33486-91, 8020), from east of Dun Raisaburgh (30799); ½ mile W. of Kilt Rock (31326); Meall Brataig (near Kilmaluag) (31327), Lon Ostatoin (31330), Druim na Slochd near Flodigarry (38021-2). The northernmost inclined sheet at Oisgill Bay, 55 ft thick, is olivine-dolerite in its centre (38070, 38073) but the later intrusion into it, only 4 ft thick, has crystallized as olivine-phyric basalt (38072).

Alteration in these rocks is usually confined to partial conversion of olivine into chlorite or bowlingite. It is interesting to note that although on the average the dimensions of the olivines in the rocks of the sills are similar to those of the phenocrysts of this mineral in the olivine-basalts of the lava-pile (see p. 105), the plagioclase and the augites are decidedly coarser in the sills. The exception to this rule is provided by the Vaternish-type lavas where both these minerals exceed in average dimensions their counterparts in the sills (p. 111).

Marginal types. In spite of the excellence of the exposures of the sills in N. Trotternish, fresh material at or near their contacts with the enclosing rocks is not easy to obtain. At Oisgill Bay, the 3-inch chilled rock at the base of the northern inclined sheet (38068) contains a few chlorite pseudomorphs after olivine of 0·5 mm diameter, labradorites of 0·1 mm, and tiny clinopyroxene granules in a groundmass of glass devitrified to a green mineraloid; chabazite and thomsonite occupy cavities. The adjacent lava (38067) has been extensively altered to green nontronitic material. In the tachylite at the top of this sheet, the black glass remains unaltered (38079). In the central later intrusion (38071-2) glass rich in opaque granules occurs interstitially. At the contact of the lower sill on the south side of the Bay with the '*Estheria*' Shales, a selvedge of opaque glass 0·2 mm thick is found; zeolites have been introduced into the shale, and the adjacent margin of the dolerite gives the impression of containing an abnormal amount of magnetite in tiny granules, as well as small altered olivines and labradorites. These marginal rocks are interesting as showing that the presence of intersertal glass is not an adequate criterion for the identification of a rock as a tholeiite; they are contact rocks of typical alkali dolerites.

In the case of the thicker sills, the rock may remain holocrystalline right up to the contact. Slices across the top contact of the lower sill at Rubha Hunish (38028-30) against shale, show a progressive reduction in average length of labradorites from 0·5 mm at 20 ft below the top (38027) to 0·3 mm 5 ft below and, about 0·2 mm in contact with the shale, which has been brecciated by the magma. The shale is hornfelsed, with the development of fine-grained biotite and tiny, parallel-extinguishing needles, probably of sillimanite. The pyroxene in the sill ceases to be ophitic 5 ft from the contact.

At the Loch Mealt waterfall, the lowest specimen (33483) is porphyritic, with stellate clusters of bytownite crystals and with pseudomorphs after olivine in a groundmass of 0·1 mm labradorites, intergranular clinopyroxene and titanomagnetite. The grain-size gradually increases above this (33484-5).

The implication of these observations is that olivine and calcic plagioclase were already present as crystals when the magma was intruded. No olivine, however, as coarse as that in the central parts of the dolerite and picrodolerite has been found in the marginal rocks, so that it appears that olivine continued to separate after intrusion.

PICRODOLERITE

The sills exhibit regions of profound enrichment in olivine, where the rock-type approaches an ultrabasic composition. Walker (1932) has used the terms picrite-dolerite for those rocks from the North Skye sills with 20-50 per cent olivine, and picrite for those with 50-70 per cent. It might be objected that the original picrite of Tschermak (1866) was an olivine-teschenite, in which the calcium and aluminium are mainly combined in analcime, whereas the present rocks always contain an appreciable feldspar content. However, picrite is a term well established in Scottish petrography for the olivine-rich differentiates of alkali dolerites. Few of the slices in the Geological Survey collection show as

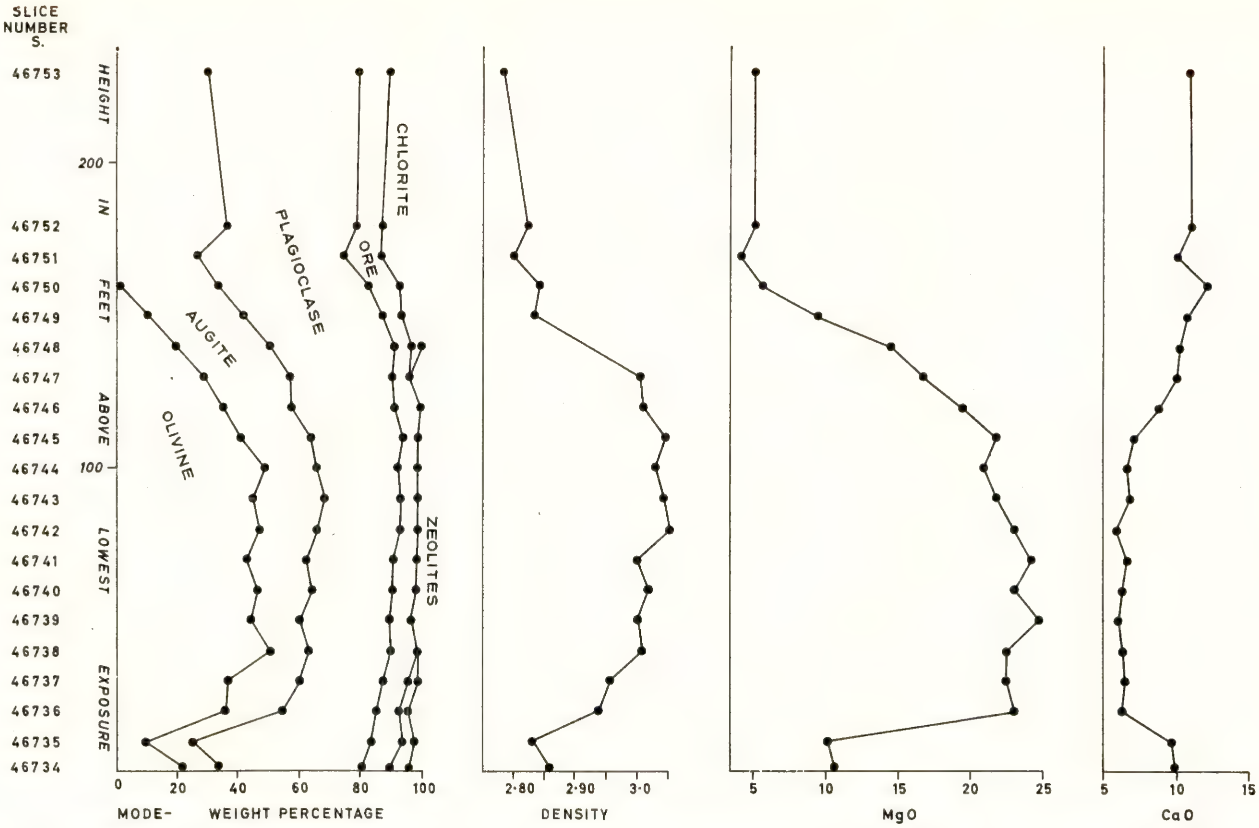


FIG. 15. *Modes of a suite of specimens collected at intervals in the central chimney cutting the Meall Tuath upper sill, Rubha Hunish. Density determinations and estimates of magnesia and lime are given for comparison. Densities by G. Wilson, chemical determinations by R. Lambert, Durham University Geology Department,* 1962

much as 50 per cent olivine, and it is considered that the term picrodolerite, recently applied by Drever (1953) to the rocks above the picrite on Garbh Eilean, adequately covers most if not all the olivine-enriched rocks of Trotternish.

The Meall Tuath cliff at Rubha Hunish has already been mentioned as exhibiting a picritic layer, with dolerite below and above. This has been investigated in more detail by collecting at 10-ft vertical intervals up the chimney which transects the cliff, starting from the lowest exposure above the scree and continuing, with a 30-ft break, to the cliff top. Unfortunately the bottom contact of the upper sill is not exposed but the lowest specimen is believed to be within 20 ft of the base. The results of modal analyses of the suite (46734-53) are summarized in Fig. 15, and compared with rock densities and determinations of MgO and CaO which serve to confirm the general picture derived from the modes. The lowest rocks are normal olivine-dolerites, but from 20 ft up the exposed section, the olivine-content shows a progressive though apparently non-linear increase up to a maximum at 40 to 100 ft, above which it falls off, declining to zero at 160 ft, not less than 120 ft below the top of the sill, the roof of which has been eroded off. The picrodolerite in the enriched region characteristically shows an abundance of rounded or subangular olivines, the largest crystals reaching 4·5 mm long but generally lying within the range of 0·5-3·0 mm. Although several crystals may be in juxtaposition, they do not form interlocked aggregates. The maximum size of the olivines of the picrodolerite is decidedly greater than those of the underlying dolerite, which hardly exceed 1·0 mm. In composition, as determined from refractive index measurements, the olivines are magnesian, Fa_{17} to Fa_{23} and showing little obvious zoning; it will be noted that their composition is close to that in the Garbh Eilean picrite as determined by Johnston (1953); whereas a wide range of zoning was found in the picrodolerite there. The plagioclase in the basal dolerite at Meall Tuath and in the picrodolerite is identical in size, not exceeding 0·5 mm; the composition range is An_{72} to An_{28} but the bulk is in the labradorite category. Pale brown augite ophitically encloses the plagioclase but seldom mantles the olivine. Titanomagnetite is present, and small amounts of zeolites and chlorite.

As the olivine dies out above the picrodolerite level, a significant change in the texture as well as the composition of the rock occurs. The feldspar becomes coarser, the maximum length of the crystals increasing to 1·0 mm. The augite not only becomes more abundant, but over a restricted range represented by the specimens from 150 to 160 ft (46749-50), shows evidence that it began to crystallize before the feldspar, in that the larger crystals are free from included plagioclase. A later generation, now intersertal to the feldspar mesh, also occurs. Still higher in the intrusion, the coarse ophitic habit of the augite is resumed; but fresh olivine continues to be totally lacking. Some of the chlorite recorded in the modes at the three highest levels sampled (46751-3) is in the form of pseudomorphs which may represent former olivines, but even so, the amount of olivine originally present was insignificant compared with that in the 'enriched' layer. It would be notably less than in the 'normal' dolerites.

The upper sill at Rubha Hunish thus shows three zones, transitional into one another: (1) normal olivine-dolerite at the bottom, probably 40 ft thick; (2) picrodolerite, 120 ft thick if the dividing line is placed at 20 per cent olivine; (3) non-olivine bearing dolerite, succeeded upward by dolerite with only insignificant amounts of olivine (now pseudomorphed in chlorite), at least 140 ft thick.

Discussion of the place and mechanism of olivine concentration will be deferred to the next chapter.

Other examples of sliced picrodolerites come from N. of Kilmuir Church Yard (31331); Carn Mor Quarry, Duntulm (32268).

CRINANITIC AND TESCHENITIC DOLERITES

Another cause of variation in the texture and composition of the sill rocks is the substantial fluctuation in the content of zeolites, especially analcime and thomsonite. Zeolites are normally present in amounts of 2-3 per cent in the olivine-dolerite and picrodolerites; but when this amount is substantially exceeded, the rocks pass into categories to which the terms crinanite and teschenite have been applied elsewhere in Scotland.

Crinanite was defined by Flett (1909) as a rock transitional between camptonite and dolerite rich in analcime. In an extended definition (Flett *in* Cunningham Craig and others 1911, pp. 42-3) he stated:

> 'The *crinanites* . . . are dark-coloured fine-grained basic rocks . . . consisting mainly of olivine, augite and plagioclase felspar, with a considerable amount of analcite and zeolites. Olivine is abundant in small grains . . . The augite is always purple . . . but the depth of colour varies in different crystals . . . The augite has a marked dispersion of one of the optic axes and shows hour-glass and zonal structures . . . The felspar . . . belongs mostly to labradorite, though the outer zones are more rich in soda . . . The iron oxides form irregular plates often fringed with scales of dark brown biotite. Most of these rocks have very perfect ophitic structure . . . Perfectly transparent analcite is not uncommon, but often this mineral is turbid and granular with weak double refraction. The radiate zeolite appears to be mostly natrolite . . . The crinanites [occur] as narrow vertical dykes . . . '

Although the original definition was extended by G. W. Tyrrell (1928) to cover the much coarser rocks of the four large sills in south-central Arran, it does not appear that the zeolite-bearing rocks of North Skye can properly be described as crinanites within its strict terms; they are not only coarser than the type rocks, but they are not dyke rocks, their pyroxenes are not appreciably purple and they do not carry biotite.

It is therefore proposed to describe as crinanitic dolerites those rocks in the Trotternish sills which contain over 3 per cent zeolites occurring in an intersertal relationship with feldspar, or filling subvesicular spaces. Good examples come from the lower sill at Rubha Hunish (38026-29) where the analcite surrounds and encloses automorphic pyroxene and plagioclase, without attacking the latter. In such a case the impression is gained that analcite, with associated thomsonite, are the last minerals of the pyrogenic sequence. Other examples come from 1200 yd S. of Kilmuir School (31328), from ½ mile N. of Duntulm Castle (31334), from Mingay Island (31346) and from localities near Loch Fada (31463-4). There appears to be no regularity in the development of this variant of the olivine-dolerite.

The same is true of the teschenitic variety. This is distinguished from the crinanitic type by the fact, well brought out in Walker's (1923) definition, that the plagioclase is partly or wholly replaced by analcime. This criterion has been accepted very generally in British petrographic nomenclature. The analcime, sometimes accompanied by other zeolites, here shows evidence of a hydrothermal role. Patches of teschenitic dolerite occur in the North Skye sills, for example on Ben Volovaig (33616) whence came Walker's analysed sample (p. 147); on

Eilean Trodday (31332, 37738); on Ascrib Island (31337); S. of Loch Fada (31466) and at the head of Lon Druiseach (31467). It is difficult to distinguish any factor which has controlled the distribution of these patches. On Eilean Mhuire, in the Shiant Isles, an irregular mass of teschenite in the upper sill passes into syenite according to Walker (1930), but this rock type is not represented in the Geological Survey collection from Trotternish.

PEGMATITIC DOLERITE

In the small islands of the North Minch, Walker (1931) identified bands of coarse gabbroid material traversing the normal dolerite, showing unchilled margins and interlocking junctions with the normal rock. Similar bands have

TABLE X

ANALYSES OF DOLERITES AND RELATED ROCKS

	N	O	P	Q	R	S	T	U
SiO_2	40·47	40·62	45·07	46·97	47·51	47·83	43·49	50·04
Al_2O_3	5·96	8·93	14·43	15·00	17·28	15·31	14·57	14·27
Fe_2O_3	2·10	0·57	0·80	1·71	3·56	1·15	5·62	3·76
FeO	12·32	12·61	10·69	8·94	5·77	9·22	7·40	6·33
MgO	29·32	26·31	14·61	10·52	5·98	6·60	5·32	5·99
CaO	4·91	5·64	9·74	10·70	11·47	12·38	11·61	12·11
Na_2O	1·18	1·32	1·75	2·18	2·60	2·53	2·92	3·41
K_2O	0·40	0·13	0·34	0·63	0·79	0·40	0·92	0·83
H_2O+	1·12	2·19	1·05	0·38	1·40	1·28	3·58	0·79
H_2O-	0·59	0·61	0·35	0·63	1·30	0·28	1·39	0·40
TiO_2	1·50	0·82	0·83	1·59	1·80	2·86	2·95	1·89
P_2O_5	0·26	0·15	0·10	0·12	0·12	0·16	0·40	0·24
MnO	0·23	0·39	0·33	0·37	0·13	0·36	0·12	0·28
BaO	—	—	0·01	—	—	—	—	—
CoO NiO	—	0·03	0·02	—	—	0·02	—	—
CO_2	—	0·03	0·02	—	—	0·05	—	—
Cl	—	0·01	—	—	—	0·01	—	—
	100·36	100·36	100·14	99·72	99·71	100·44	100·29	100·34

N. Picrite, top of cliff W. of Camas Mor; analyst N. Sahlbom *in* Walker 1932, p. 247.
O. Picrite, S. face of Garbh Eilean, Shiant Is., by the shingle beach; analyst E. G. Radley *in* Walker 1930, pp. 371-2.
P. Olivine-dolerite (picrodolerite of present account), Garbh Eilean 30 ft above the beach; analyst E. G. Radley *in* Walker 1930, pp. 371-2.
Q. Olivine-dolerite (" normal dolerite "), just S. of mid-point of S.W. shore. Fladda-chuain, analyst N. Sahlbom *in* Walker 1931, p. 757.
R. Olivine-dolerite (" normal dolerite "), Loch Mealt near Waterfall, 80 ft above lower contact; analyst, N. Sahlbom *in* Walker 1932, p. 245.
S. Crinanite, Garbh Eilean, 125 ft above the beach; analyst, E. G. Radley, *in* Walker 1930, pp. 371-2.
T. Teschenite, Ben Volovaig, half way up slope; analyst, N. Sahlbom *in* Walker 1932, p. 249.
U. Pegmatitic dolerite, Fladda-chuain, N. end; analyst N. Sahlbom *in* Walker 1931, p. 760.

been found 500 yd N.N.E. of Flora Macdonald's grave (32704); on Eilean Trodday (31703) and 60 yd N. of Kilt Rock, near the base of the lower sill (37736). The feldspars, which reach 2 mm long, are somewhat less calcic than in the dolerite, An_{64} being the most basic recorded. Remarkable skeletal or dendritic forms are assumed by the titanomagnetite, which reaches similar dimensions. Olivine is rare or absent, though bowlingite pseudomorphs may sometimes be found (37786). Augite is generally pale brown, and may present crystal faces to the feldspar; it commonly exceeds 4 mm. In some cases a faint greenish tint can be distinguished near the margins. A little bright green amphibole occurs (32704, 32711). Zeolites, especially thomsonite, are invariably present in quantity. Stilbite and analcime have also been identified. The pegmatitic dolerite is associated with teschenitic dolerite on Ben Volovaig (32711); but the augite is less uniform in colour, exhibiting purple and green tints as well as the usual pale brown. The two rock types may be regarded as having been influenced by the concentrated hydrothermal fluids collected towards the end of the crystallization-history of the sills.

CHEMICAL COMPOSITION

All the variants described are adequately represented by chemical analyses published by F. Walker (1931) and it has not been considered necessary to undertake further rock analyses apart from the magnesia and lime determinations for

TABLE XI

NORMS AND MODES OF DOLERITES AND RELATED ROCKS

Norms	N	O	P	Q	R	S	T	U
or	2·2	0·6	1·7	3·3	4·5	2·2	5·6	5·0
ab	4·7	3·3	14·7	17·8	22·0	21·0	19·2	28·8
an	10·0	20·8	30·6	29·8	33·4	29·5	23·9	20·9
ne	2·8	4·1	—	—	—	—	2·7	—
di	9·9	5·7	13·5	18·2	18·5	25·4	24·7	29·6
hy	—	—	0·8	5·9	7·8	6·2	—	7·6
ol	62·3	61·5	33·9	17·8	2·2	7·1	4·1	3·3
il	2·9	1·5	1·5	3·0	3·5	5·5	5·6	3·7
mt	3·0	0·6	1·2	2·6	5·1	1·9	8·1	5·3
op	0·7	0·3	0·3	0·3	0·3	0·3	1·0	0·4
Normative Or			4	6	7	4		9
Plagioclase Ab			31	35	37	40		53
An			65	59	56	56		38
Modes								
Olivine	66	59*	31*	18	9½	12*	7½	—
Augite	14	10	17	23	23½	24	22	27½
Plagioclase	17½	26	50	51½	60½	60	46	52½
Titanomagnetite	2½	2	2	6½	5	3	11½	8
Zeolites	—	3	—	1	1½	1	12	12
Apatite	—	—	—	—	—	—	1	—

* It is not certain that these correspond with the analysed specimens though they are from the same localities.

the 20 rocks of the Meall Tuath suite (Fig. 15). Those for rocks from the Rubha Hunish (90) Sheet are reproduced in Table X, with the three main types from Shiant for comparison. The picrites and picrodolerite show, as would be expected, high MgO and FeO contents, and a low Fe_2O_3/FeO ratio. These are considered to be olivine cumulates, with interstitial dolerite. The teschenitic and pegmatitic types show much higher Fe_2O_3/FeO ratios, and also display distinct enrichment in Na_2O and a slight enrichment in K_2O as compared with the normal and crinanitic dolerites. Combined water is very high in the teschenitic variant, where, according to Walker, 12 per cent zeolites (including analcime) are present. The apatite content of this rock is higher than normal, but fluorine was unfortunately not determined in the analysis; that concentrated volatiles influenced this type is supported by the chemical and modal data.

PETROGRAPHY OF THE DYKES

General. Of the very numerous dykes exposed in the area of the Portree and Rubha Hunish (90) sheets, a total of 177 have been sliced. Although this number cannot be regarded as a true sample, the distribution of rock-types, summarized in Table XII, perhaps gives some indication of their relative importance. The types are listed in the order in which they are to be described.

TABLE XII

THE DYKES OF NORTH SKYE

Rock-Type	*On One-inch map*	*No. of Slices*
Normal olivine-dolerite and basalt	K^D	21
Normal crinanitic variants	K^C	43
Picritic dolerite [Picrite on map]	fU°	7
Mugearite, including feldspar-phyric types	X^M	12
Variolite	vK	6
Leidleite	P^L	1
Trachyte	O^T	1
Feldspar-phyric dolerite and basalt, including crinanitic variants [Dolerite, basalt or Tholeite (unclassed)]	K^D	32
Allivalite, olivine-eucrite [E′gabbroic (unclassed)]	U^A, E′	15
Tholeiitic dolerite and basalt	K^T	29
Tholeiitic feldspar-phyric dolerite and basalt	K^T	13

As already noted in the account of field relations, many of the dykes are of compositions similar to the lavas exposed in the same part of the island. This applies to some of the olivine-dolerites and basalts, which include olivine-phyric types; to the mugearites and the trachytes, and to a few of the feldspar-phyric dolerites and basalts, in which the feldspar phenocrysts are no more calcic than labradorite. On the other hand, the bulk of the feldspar-phyric dykes carry calcic bytownite or anorthite phenocrysts, and these rock types are not known to be represented among the lavas; the 'big-feldspar' mugearite lavas contain phenocrysts of labradorite composition. No lavas corresponding to the allivalites or olivine-eucrites are known, and this fact makes it difficult to believe that these curious lenticular dykes or pods acted as volcanic vents. The sliced rocks from North Skye include no lavas as olivine-rich as the picritic dykes, though one lava described by D. Almond (1964) from Strathaird compares with them. These dykes may well represent injections of olivine-cumulus from the sill system. The tholeiitic types, which carry little or no olivine and contain an intersertal mesostasis that may, at an earlier stage, have been glass, are likewise not represented among the lavas save by the pillow-lava of Creag Mor (p. 102). It is very noticeable that not a single quartz-dolerite has been found in North Skye, and the supposed tholeiites fail to reveal any examples comparable with the silica-rich Talaidh and Brunton types of Mull (Bailey and others 1924, pp. 301, 372). The situation in Skye generally is that rock-types referable to the tholeiitic lineage are very much rarer than in Mull, if indeed, they exist at all in significant quantities.

NORMAL OLIVINE-DOLERITE AND BASALT

It has already been noted that the lavas include a class of dolerites (with the average length of the feldspar tablets greater than 0·5 mm) as well as basalts, but that there is no evidence of major differences in composition between the two types. In the case of the dykes, rocks which are texturally dolerites are somewhat commoner than basalts, but both occur in the suite and the artificial nature of the distinction is again evident.

Another comparative point of some interest is that whereas ophitic crystallization of the augite is very widespread both in the lavas and the sills, in the dykes the intergranular texture is commoner. Here small crystals of clinopyroxene sometimes showing crystal faces, nestle in the interstices of the mesh of feldspars. Good examples include 31453, 32714, 33844, 33858, while ophitic types are represented by 33961.

The olivines in these dykes are usually rounded, as in the lavas and sills, though occasionally tabular, automorphic forms appear (e.g. 31965, where the olivine seems to enclose some feldspar). For the most part, the olivines appear to have begun to crystallize before the magma was injected into the fissures; this is borne out by the presence of olivine phenocrysts in tachylite glass at the margins of the dykes (e.g. 31430, 33958). Generally the olivines do not enclose any other mineral except titanomagnetite. The size range is up to 1·25 mm diameter, and forsteritic compositions, similar to those in the lavas are characteristic.

The feldspar mesh is made up of zoned crystals in which the bulk composition lies within the labradorite range. Occasionally the centres are more calcic and usually there are thin marginal zones of andesine or even oligoclase.

The clinopyroxene is usually pale-coloured in thin section, not colourless when compared with olivine, yet with no well defined tint beyond a vague grey or pale brown in most cases. A few examples, however, show definite purple colouration and faint pleochroism (e.g. 31974, 22874). In no case has orthopyroxene, or pyroxene with a low optic axial angle, been found in these rocks. Diopsidic augites occur in every case investigated.

The crystallization in the normal types is completed by the titanomagnetite, often automorphic or skeletal in outline, and no mesostasis is present. However, some glass usually occurs close to the contact with the country rock.

CRINANITIC VARIANTS

In the crinanitic variants, zeolites are present in addition to the minerals described above, but the pyrogenic constituents continue to appear in much the same proportions. True crinanites, dyke rocks corresponding with the definition of Flett cited on p. 146 do occur, but they are rare. Examples include 31417, 31429, 31592, 33841. Two rocks from Geo Mor (33846) are coarser than normal, but otherwise of crinanite compositions; they contain olivines up to 1·5 mm long, the labradorite (An_{67} maximum) forms a mesh of crystals 1-1·5 mm long; the ophitic augite is a definite purple colour by transmitted light and varies up to 2·5 mm diameter; titanomagnetites are 0·1 mm on the average and a few per cent analcime is present. Most of the dykes classed as crinanitic, however, fail to meet Flett's definition in that the augite is intergranular rather than ophitic, and in many cases it is not purple in colour. Zeolites, including analcime, thomsonite and chabazite are present in vesicles or in spaces in the mesh.

Some of the dykes in this subclass closely resemble the alkali-basalt lavas in that rounded, or in some cases automorphic olivine phenocrysts are present (e.g. 33956, 33959, 31592, 32710, 33836, 36209). These range in size between 0·5 and 2·5 mm, and may be enclosed in a basaltic or doleritic matrix. It is not difficult to believe that dykes of this sort acted as feeders for the olivine-phyric alkali basalts which form the predominant lithology in North Skye. The dyke in Gob na Hoe (36210-2) forms a striking example. Well formed olivines up to 2·5 mm long are enclosed in a mesh of 0·5 mm labradorites, with purple intergranular and subophitic augite, automorphic titanomagnetites of 0·1 mm, and a little analcime.

Other members carry only very small olivine crystals, though often in some abundance (e.g. 31969, 31872, 32709, 32944, 33835) and these are not readily correlated with the plateau lavas.

At the margins of the crinanitic dykes, chilling has caused glass to form. This may be vesicular, with minerals such as thomsonite, analcime, chabazite and chlorite in the vesicles (e.g. 31347 from Rodmor Peninsula). Extreme zeolitic alteration is not particularly common in the dykes, though in a rock from Allt Dearg (33992) the feldspars have been almost totally replaced.

PICRITIC DOLERITES—PICRITES

A few olivine-rich dykes of ultrabasic aspect have been found. Both in mineralogy and texture they are virtually identical to the picrite dolerite layers in the Trotternish sills. The olivines range up to 5 mm diameter; typically they are well rounded and a representative example from Breabost Burn, E.N.E. of Dun Flashader (33981) revealed a composition as indicated by refractive index measurements, of Fa_{13}, the most magnesian olivine recorded in the area. The matrix of the rock consists of small labradorite crystals not more calcic than those in the normal dolerites; subophitic pale greyish or brown augite and hypautomorphic titanomagnetite. Zeolites, including especially thomsonite are present in some instances (33908, 33971). In two cases, a dyke from the summit of Ben Geary (31339), and another from Allt Yelkie (31414) the proportion of olivine considerably exceeds 50 per cent, and since zeolites are present the rocks are true picrite in accordance with the original definition of the term. In both rocks some brown chrome-spinel is present. The feldspar in these rocks shows zonal ranges of An_{68-60} and An_{70-40} respectively, (the lower estimates being the less satisfactory), and has been attacked by zeolitic alteration. In the field, the picrites and picritic dolerites are recognizable by the abundance of yellowish olivine.

MUGEARITE

In appearance, the mugearite dykes, like the lavas of this composition, are recognizable to the experienced observer by their black colour, very fine grain, their platy fracture (in the dykes it is usually parallel to the walls) and their tendency to form a thin brown or reddish brown crust upon weathering. Under the microscope, they are hardly distinguishable from the lavas. The chief constituents are oligoclase (or more probably potash oligoclase and anorthoclase—see p. 164), tiny augite granules, microphenocrysts of olivine more fayalitic than in the other dyke rocks, and an abundance of tiny octahedra of titanomagnetite. The feldspars range from 0·04 mm (37732) to 0·4 mm (31403), the average seldom exceeding 0·2 mm long. In most of the sliced rocks, secondary alteration, especially chloritization of olivine, zeolitization of feldspar and introduction of analcime and chabazite into gas cavities has occurred, giving the impression that the dykes have been more subjected to the movement of hot waters than the centres of the exposed lavas such as those of Hartaval and the Roineval area. The freshest example is from a dyke, the centre one of three exposed in Dubh Allt, a stream crossing the Portree-Sligachan road near Beinn na Greine (38005). Here the olivines are less than 0·1 mm diameter, and there are a few labradorite phenocrysts up to 0·5 mm long. A lava exposed a little above the dykes (38007) is very similar though a little coarser and though the junction is not seen, it is permissible to think that the dykes might have been the sources of the flows. Other examples of mugearites come from Voaker Burn (31398), the shore of Loch Caroy (31403), from N.E. of the road bridge over Vidigill Burn (34181), the Tungadal River (34186), from Allt an Lon Ghuirm, S.E. of Edinbain (36229) and from a stream 640 yd E.N.E. of Garadubh (37753, 37755).

None of our sliced specimens is a big-feldspar mugearite, comparable with the Roineval lavas (p. 120) and it is not certain that dykes of this remarkable rock type have been located. Small phenocrysts of composition respectively An_{64} (31394) and An_{28} (37792) have been found in two dykes.

Probably the best-known example of a mugearite dyke in North Skye is that of Am Bile, exposed 1¼ miles E.N.E. of Portree. J. W. Judd and G. A. J. Cole (1883) described the two-inch glassy selvedges of this dyke, and cited the following analysis by Hodgkinson: SiO_2, 50·29; Al_2O_3, 17·33; Fe_2O_3, 11·14; MnO, 0·66; CaO, 6·17; MgO, 2·62; Na_2O, 4·24; K_2O, 2·40; Loss on ignition, 3·27; Total, 100·72. Harker (1904, pp. 331-2) gave a petrographical description of the mugearite, which in the centre is coarser than that of Druim na Criche (9373-5).

VARIOLITE

A small but well defined group of dykes shows characteristics that may be regarded as consistent with the usage of the term variolite as adopted by Harker (1904, p. 347) and the authors of the Mull Memoir (Bailey and others 1924, pp. 150-1) though it should be noted that in Mull these rocks characteristically form the carapaces of pillow lavas. In the field, the dykes are pale grey or bluish-grey, fine-grained, often containing vesicles which may be empty, or filled with zeolites or a black mineraloid. Under the microscope they are found to be dominated by stellate groups or radiating sheaves of fine acicular or platy feldspars, the composition of which, according to their optical properties lies between An_{10} and soda anorthoclase. Pyroxenes also occur in the form of thin prisms with an acicular tendency; they are, without exception, augites but their exact position with respect to the iron end of the series has not been determined. Acicular amphiboles also occur in some cases, pale-brown or green (37724, 37751). Brown biotite also occurs in tiny flakes and minute octahedral or rods of titanomagnetite and accessory apatite complete the pyrogenic assemblage. A variable amount of material which was formerly glass but is now represented by fine devitrification products, may form a background to the rock (37729). Analcime and chlorite both commonly occur as late or secondary minerals (31431). Good examples of variolite dykes come from the S. end of Creag Langall (31431), the Snizort River, 660 yd W.S.W. of Uigshader (31445) and 1 mile S. of the trigonometric point on Sithean Bhealaich Chumhaing.

LEIDLEITE

A single example of a rock comparable with the stony type of leidleite of the Mull Memoir (Bailey and others 1924, pp. 281-2) found during the field survey was identified by Mr. E. H. Francis. The rock has a pale bluish tint, is fine-grained and is riddled with vesicles most of which are empty, though a few have white mineral linings. In thin section it shows acicular yellow-brown amphiboles, 0·1-0·2 mm long set in a matrix of ill-defined feldspar of feathery rather than tabular form, though in places stellate groupings can be seen. The feldspar is an untwinned alkali type, perhaps anorthoclase. No glass is present. Some vesicles are rimmed with alkali feldspar. The single example (31747) comes from the Tungadal River.

TRACHYTE

Trachyte dykes are poorly represented in the collection from the present area, but as noted above, Harker (1904, p. 58) has already described the Drynoch group in Bracadale Burn. There is little to add; the rocks are very pale grey in the field, and carry sparse visible phenocrysts of augite and biotite. One example, collected 450 yd N.W. of the bridge in Glen Vidigill (31388) contains a little olivine, and some clinopyroxene; it represents a type transitional between mugearite and trachyte comparable with the lava of Analysis IX, p. 121. The exact nature of the alkali feldspar which forms the bulk of the rock in these dykes requires refined study of fresh material; probably it is anorthoclase or sanidine. One specimen contains corroded xenocrysts of albite. Apatite needles, seldom seen in the basic dykes, are noticeable in these.

FELDSPAR-PHYRIC DOLERITE AND BASALT

As Table XII shows, feldspar-phyric dolerite and basalt dykes form an important element in the swarm and are treated separately because they present a petrogenetic problem, in carrying abundant phenocrysts of bytownite or anorthite, that does not apply to any of the lavas save the big-feldspar mugearites. Most of the present group of dykes have no counterpart among the lavas, though a few, notably 33834 from the eastern base of Knock Vatten, 31421 from 275 yd N. of the ruins of Caisteal Disdein and 33859 from a quarry S.E. of Fairfield Cottage contain labradorite phenocrysts and could have been the feeders of feldspar-olivine-phyric basalts such as those listed on p. 115. For the rest,

TABLE XIII

ANALYSES AND NORMS OF ALLIVALITE AND EUCRITE

	V	XII	Y	Z
SiO_2	47·33	44·95	48·28	47·28
Al_2O_3	20·08	24·02	20·38	21·11
Fe_2O_3	0·55	0·93	1·78	3·52
FeO	3·24	4·07	6·70	3·91
MgO	12·53	9·43	7·93	8·06
CaO	14·47	13·70	11·80	13·42
Na_2O	1·34	1·21	1·75	1·52
K_2O	0·07	0·11	0·14	0·29
H_2O+	0·21	1·27	0·76	0·53
H_2O-	0·14	0·48	0·09	0·13
TiO_2	0·15	0·13	0·23	0·28
P_2O_5	tr	0·02	0·02	tr
MnO	0·08	0·08	0·28	0·15
CO_2	—	tr	0·03	—
S	—	0·01	—	—
Cr_2O_3	0·18	0·05	—	—
NiO	—	0·01	—	—
BaO	—	0·01	—	—
SrO	—	0·02	—	—
Li_2O	—	nt. fd.	—	—
FeS_2	—	—	0·04	—
	100·37	100·50	100·21	100·20

Norms

		V		XII		Y		Z	
	or	0·56		0·56		0·56		1·67	
	ab	11·32		9·96		14·67		12·58	
	an	48·93		59·77		47·54		50·04	
	ne	—		—		—		—	
di	wo	9·55	18·09	3·48	6·64	4·52	8·77	6·96	13·32
	en	7·26		2·50		2·80		5·20	
	fs	1·28		0·66		1·45		1·06	
hy	en	—		1·80	2·46	12·60	19·46	9·70	12·08
	fs	—		0·66		6·86		2·38	
ol	fo	16·70	19·96	13·44	17·52	3·08	5·12	3·64	4·66
	fa	3·26		4·08		2·04		1·02	
	mt	0·79		1·39		2·55		5·10	
	il	—		0·24		0·53		0·61	
	ap	—		0·04		0·04		—	
	cr	—		0·06		—		—	
	ca	—		—		0·07		—	
	py	—		·002		0·04		—	

Plagioclase $Or_1Ab_{18}An_{81}$ $Or_1Ab_{14}An_{85}$ $Or_1Ab_{23}An_{76}$ $OR_2Ab_{20}An_{78}$

however, the phenocrysts are very calcic and the zoning within them shows a marked break, the outermost zones corresponding with the labradorite found as small crystals in the matrix.

The phenocrysts tend towards a certain constancy of size, as if they had in some way been graded; few of the bytownite-anorthites are less than 2 mm or more than 5 mm long. Their calcic compositions are sufficiently evident from measurement of maximum extinction angles in the 'symmetrical' zones but they show complexity of twinning and parallel growth, where aggregated, so that the use of the more accurate Albite-Carlsbad method is fraught with uncertainty. Refractive index measurements of ten representative examples covering all possible varieties of matrix gave the following figures for maximum anorthite-content: An_{70} (30790), An_{84} (31348), An_{90} (31351), An_{90} (31976), An_{92} (32716), An_{87} (32934), An_{77} (33849), An_{80} (33981), An_{93} (33986), An_{88} (36237). Estimates of the break in the zoning have been attempted in a number of cases, these gave results as follows: An_{77}/An_{57}, (33849); An_{93}/An_{78} (33986); An_{75}/An_{65} (34002), the stroke representing the range of composition apparently missing.

Olivine is usually present in these dykes as phenocrysts or early crystals, but in size it is invariably inferior to the feldspars. In only one case does the olivine reach 1 mm diameter (32717).

A variety of matrices are displayed. Of the 32 rocks sliced, half are classified as dolerites, half as basalts. In only one case (33990) is there clear evidence of a second generation of olivine crystallization, but labradorite, locally crystallized, is invariably present. As in the other dykes, the augite is generally very pale in colour, though purple tints were noticed in a few cases (31975, 30790). The Intergranular habit is commoner than the ophitic, only seven out of 32 rocks showing the latter in well-developed form. Titanomagnetite is invariably present.

Crinanitic types with up to 10 per cent zeolites are included in this class, 12 rocks falling into this group. Chabazite, analcime, thomsonite and stilbite were noticed; one rock (31417) shows a very spectacular development of thomsonite.

ALLIVALITE, OLIVINE-EUCRITE, GABBRO

Perhaps the most interesting dykes of North Skye are the coarse, phanerocrystalline intrusions which occupy a series of linear broad lenses or pods, trending N.N.W. (p. 136). In these the texture is not doleritic but gabbroid, made up of xenomorphic interlocked crystals of calcic plagioclase, olivine, clinopyroxene and titanomagnetite. The rocks are classified as allivalite when the anorthite-content

---

KEY TO TABLE XIII

V. Allivalite from Unit 10 of the Layered Series, Hallival, Rhum; Analyst, G. M. Brown 1957, p. 47.

XII. Allivalite, Broisgillmore Burn, ½-mile S.S.W. of summit of Am Bidean, Skye; Analysts W. F. Waters and K.L.H. Murray, Geological Survey Lab. No. 1576, 1950. Guppy and Sabine 1956, p. 24.

Y. Gabbro-variant of Great Eucrite Ring-dyke, Centre 3. Ardnamurchan W. side of Creag an Airgid, 1¼ miles S. 40° E. of Achnaha; Analyst E. G. Radley, Geological Survey Lab. No. 736 *in* Richey and Thomas 1930, p. 85.

Z. Olivine-gabbro (Eucrite). Major intrusion. Coir' a'Mhadaidh, Cuillins, Skye. Analyst, W. Pollard *in* Harker 1904, p. 103.

of the plagioclase exceeds 80 per cent; olivine-eucrite when it is in the range An_{70}-$_{80}$ and gabbro when it is less than 70 per cent, in accordance (as far as allivalite is concerned) with the proposals of G. M. Brown (1957, p. 12), in his recent work on the type allivalites of Rhum, and as far as eucrite is concerned with those of W. J. Wadsworth (1961, p. 28).

Most of the dykes sampled belong to the allivalites and contain calcic bytownite or anorthite as their main constituent. As representative of them, a rock from the centre of the lens exposed in Broisgillmore Burn, ½ mile S.S.W. of the summit of Am Bidean (37870) has been analyzed (Table XIII). The rock is grey, gabbroid in appearance, and is composed of plagioclase crystals exhibiting mutual boundaries, the composition as estimated from refractive index determinations being An_{90}, and as calculated from the rock analysis An_{85}. Rounded fresh olivines with intermediate refractive index 1·710 (corresponding with 27 per cent fayalite) are enclosed by ramifying pale green salitic clinopyroxenes with $\beta = 1{\cdot}703$ and moderate optic axial angle. A few magnetite crystals are present, but these are not common. Among late-stage effects, chlorite-bowlingite veinlets cut the ferromagnesian minerals, and there is some alteration of the feldspar to a member of the thomsonite family having intermediate index 1·544. Another sliced rock from the left bank of the burn is similar (31410); extensive zeolitization and serpentinization is seen in places (31411). Towards the margins of the lens the rock begins to assume a porphyritic aspect; this is due to the fact that while the coarse minerals described above continue to be present they are now enclosed in a doleritic matrix with labradorite and ophitic augite (31412). This observation is believed to be of some petrogenetic significance (p. 170). The lens as at present exposed is intrusive into 'big-feldspar' mugearite, with bytownite phenocrysts in a fluxion groundmass of alkali feldspar (31413).

The analysis of the rock from the centre of the lens shows that the rock is somewhat more feldspathic than allivalites from the type locality analysed by G. M. Brown (1957) but the feldspar composition leaves no doubt as to the correctness of the classification. Olivine greatly predominates over pyroxene; whereas in the eucrites cited in Table XIII the reverse situation obtains, and the feldspar is a little less calcic.

A rock closely similar to the analysed specimen comes from 1560 yd N.N.W. of the Manse at Bracadale. The feldspar composition in An_{84}; the plates, which range up to 4 mm across, enclose crystallographically oriented inclusions, apparently of glass. The olivine carries 26 per cent fayalite and zeolites are again present, especially thomsonite. In a rock from the dyke forming the waterfall in Voaker Burn (31402) the feldspar again shows inclusions, and is zoned An_{80} to An_{70}. The very pale green augite contains rod-like inclusions, probably of pigeonite. In this rock, a second, smaller generation of feldspars occurs. Another allivalite is exposed on the shore 300 yd north of the U.F. Manse at Dunvegan (31591). In the allivalite exposed 400 yd N. of Fairfield Cottage the plagioclase (An_{86}) greatly predominates, but there is more olivine than augite; zeolites are absent. Another excellent example, with anorthite (An_{90}) crystals 4 mm across comes from 1000 yd S.W. of Beinn a'Chleirich (32933).

From the S.E. point of Ardroag (32945) comes a dyke rock which in places exhibits gabbroic texture, but in others is doleritic, the maximum anorthite-content of the feldspar is 75 per cent. The dyke 260 yd E.S.E. of Edinbain Hotel (33985) again shows a mixed texture, and the feldspar suggests a eucritic rather than allivalitic composition; there are also thin, sharp zones of sodic plagioclase around the larger crystals. The rock from what may be a plug at Creag Bhreac, 800 yd E. of the Beinn na Cloiche is on the allivalite/ecurite boundary and again shows the admixture of large interfering plagioclases with small tabular crystals.

Summarizing, it appears that with small variations in the composition of the plagioclase which forms 60-70 per cent of these rocks, both allivalites and olivine-eucrites are present. Olivine is normally twice as abundant as clinopyroxene. Some of the rocks are gabbroid and phanerocrystalline; others contain an admixed doleritic mesh.

THOLEIITE

About one-third of the doleritic or basaltic dykes examined have proved to have two properties in common; a paucity or total absence of olivine, and the presence in the interstices of the labradorite mesh of patches of glass, or much more frequently, of chlorite or an ill-defined green mineraloid that may represent the devitrification products of glass. Although quartz is rare (in fact, only slice 33979, from 400 yd S.S.E. of Dun Flashader contains free quartz) and none of the patches show alkali feldspar, the rocks resemble closely many that have previously been classified as tholeiites in Scotland. This appears to be consistent with Rosenbusch's (1887) definition of tholeiite. As Holmes (1929) remarks, the essential features are the basaltic composition of the crystalline framework, the development of intersertal texture, and in the case of unqualified tholeiite, freedom or near freedom from olivine. Nevertheless, it must not be supposed that such rock necessarily derives from what is now accepted among petrologists as tholeiitic magma (*vide* Tilley 1952). As already noted, intrusions which manifestly belong to the alkali-basalt suite may be poor in olivine (p. 145) and may contain intersertal glass near their contacts with country rocks.

One feature of the rocks classified in North Skye as tholeiites which demands that a cautious view be taken of their origin, is the total absence from them of orthorhombic pyroxene or of pigeonite. A repeated search for these minerals has only served to reveal that all the pyroxenes investigated are, as in the "normal" basaltic rocks, diopsidic augites.

Dealing first with those dykes that carry a few per cent of olivine, it is possible to see in these comparisons with the Salen type of the Mull Memoir (Bailey and others 1924, p. 285). A good example comes from Gab na Hoe (36213-4), where a few olivines of 0·2 mm, not constituting more than 3 per cent of the rock, occur within a labradorite mesh of tablets 0·7 mm long, with intergranular pale augite, titanomagnetite and intersertal patches of dark glass. Other examples include a specimen from 700 yd W. of Dun Borrafiach (31340); and from the Hamra River, Glendale (32916, 33855, 33857).

Probably of greater importance, both numerically and from a genetic point of view, are the olivine-free dykes that approximate to the Acklington type of Holmes (1929, p. 28). In an example from Allt Dearg (33989), thin 0·3 mm long labradorites form stellate groupings; there are intergranular colourless to very pale purple augites and smaller titanomagnetites; and about 20 per cent of the rock consists of fine-grained chlorite in intersertal relation to the feldspars. A similar rock, from the east side of Ard Beag (31344) is composed of labradorite, zoned from An_{70} to An_{30} averaging 0·5 mm, pale augite in granules of 0·25 mm diameter, some showing a tendency to grow round the feldspar; titanomagnetite moulded on the feldspar and dusty glass mixed with dull olive-green chlorite of low birefringence. A basaltic version of this rock is found in a dyke on the shore 910 yd S.E. of Ullinish Lodge; and there are numerous other examples (31436, 32483, 32715, 32935, 33838, 33970, 37733). A single example carries augite phenocrysts (32872).

PORPHYRITIC THOLEIITES

Dykes containing calcic plagioclase phenocrysts up to 5 mm long set in a matrix similar to the tholeiites described above are known at a number of localities. The phenocrysts are similar in appearance, shape and composition to those described in the dykes related to the alkali basaltic suite (p. 160). Determinations gave An_{92} (30784); An_{85} (31433); An_{92} (32712) while the range of zoning in the phenocrysts in 31973 is from An_{88} to An_{60}.

The matrix in some of these rocks corresponds with the Salen type (30784, 31343, 31433, 31963, 31973, 31978, 33984), others might be regarded as porphyritic Acklington types (e.g. 32712, 33028, 33839). It is, of course, well known that bytownite-anorthite occurs as phenocrysts in the Mull tholeiites, as well as in many of the dykes that swing south-eastward across southern Scotland and northern England. The significance of these phenocrysts is discussed below (p. 164).

REFERENCES

ALMOND, D. A. 1964. Metamorphism of Tertiary lavas in Straithaird, Skye. *Trans. Edin. Geol. Soc.*, **65**, 413-34.

BAILEY, E. B., CLOUGH, C. T., WRIGHT, W. B., RICHEY, J. E. and WILSON, G. V. 1924. Tertiary and post-Tertiary Geology of Mull, Loch Aline and Oban. *Mem. Geol. Surv.*

BROWN, G. M. 1957. The layered ultrabasic rocks of Rhum, Inner Hebrides. *Phil. Trans. Roy. Soc. B.*, **240** 3-52.

CUNNINGHAM CRAIG, E. H., WRIGHT, W. B. and BAILEY, E. B. 1911. The Geology of Colonsay and Oronsay with part of the Ross of Mull. *Mem. Geol Surv.*

DREVER, H. I. 1953. A note on the field relations of the Shiant Isles' picrite. *Geol. Mag.*, **90**, 159-60.

FLETT, J. S. 1909. In *Sum. Prog. Geol. Surv.*, p. 52.

GEIKIE, A. 1897. *The Ancient Volcanoes of Great Britain*, vol. II, London.

HARKER, A. 1904. The Tertiary Igneous Rocks of Skye. *Mem. Geol. Surv.*

HOLMES, A. 1929. The tholeiite dykes of the North of England. *Mineral. Mag.*, **22**, 1-52.

JOHNSTON, R. 1953. The olivines of the Garbh Eileen Sill, Shiant Isles. *Geol. Mag.*, **90**, 161-71.

JUDD, J. W. 1885. Tertiary and older Peridotites of Scotland. *Quart. J. Geol. Soc.*, **41**, 354-418.

—— and COLE, G. A. J. 1883. On the basalt-glass (tachylite) of the Western Isles of Scotland. *Quart. J. Geol. Soc.*, **39**, 444-64.

MACCULLOCH, J. 1819. *A Description of the Western Islands of Scotland, including the Isle of Man.* London.

MURRAY, R. J. 1954. The clinopyroxenes of the Garbh Eilean sill, Shiant Isles. *Geol. Mag.*, **91**, 17-31.

RICHEY, J. E. and THOMAS, H. H. 1930. The Geology of Ardnamurchan, North-west Mull and Coll. *Mem. Geol. Surv.*

ROSENBUSCH, H. 1887. *Mikroskopische Physiographie*, **2**, Stuttgart, 504.

TILLEY, C. E. 1950. Some aspects of magmatic evolution. *Quart. J. Geol. Soc.*, **106**, 37-61.

TSCHERMAK, G. 1866. Felsarten von ungewohnlicher Zusammensetzung in den Umgebungen von Teschen und Neutitschein. *S. B. Akad. Wiss. Wien*, **53**. pt. I, 260-86.

TYRRELL, G. W. 1928. Geology of Arran. *Mem. Geol. Surv.*

WADSWORTH, W. J. 1961. The layered ultrabasic rocks of South-west Rhum, Inner Hebrides. *Phil. Trans. Roy. Soc. B.*, **244**, 21-64.

WALKER, F. 1923. Notes on the classification of Scottish and Moravian teschenites. *Geol. Mag.*, **60**, 242-9.

—— 1930. Geology of the Shiant Isles (Hebrides). *Quart. J. Geol. Soc.*, **86**, 355-94.

—— 1931. The dolerite isles of the North Minch. *Trans. Roy. Soc. Edinburgh*, **56**, 753-66.

—— 1932. Differentiation in the sills of Northern Trotternish. *Trans. Roy. Soc. Edinburgh*, **57**, 241-57.

Chapter X

IGNEOUS PETROLOGY

THE INITIAL ERUPTION IN NORTH SKYE

THE EVIDENCE from North Skye shows that volcanic activity began with an explosive phase, during which crystals of magnesian olivine and labradorite were erupted with liquid magma which froze to glass. In view of the association of plant-bearing sediments and of pillow lavas with the crystal-vitric tuffs, the last named probably accumulated in water. Bombs of hyaline porphyritic basalt were thrown out at the same time. A central type of eruption is perhaps suggested, but the location of the vent is unknown; it might be concealed beneath the lavas between the Portree coast and the Halistra district in Vaternish. There is no evidence to suggest that what later became the main centre in the Cuillins was active and this stage is not known to be recorded in that area.

From the limited evidence afforded by the unaltered glass in the tuff (p. 95) and the recalculated analysis of the pillow lava (p. 99) it is suggested that the initial magma may have been more closely allied to the tholeiite lineage than to that of the subsequent alkali olivine-basalts. This view is based on (i) the higher silica-contents of these rocks (52·0; 47·6) than that of average Hebridean basalt (45·9); (ii) the absence of olivine from the C.I.P.W. norms, (iii) the lower alkali/silica ratio as compared with the Hebridean series. Soda, for example, reaches 5 per cent for a silica-content of 52 according to the plots both of the Mull authors (Bailey and others 1924, p. 26) and that of L. R. Wager (1956, p. 230), whereas it is only 3·2 per cent in the sideromelane of the 'palagonite' tuff. It is nevertheless recognized that in rocks which have been subjected to alteration, as these have, the evidence is not decisive.

THE ALKALINE OLIVINE-BASALT SUITE

General: The great pile of lavas which overlies the tuffs represents, in the main, the quiet outpouring of magma, with very little explosive activity. The lava plateaux so produced consist predominantly of olivine-basalts, but in the region between Greshornish and Mugeary, mugearites and trachytes are frequently interbedded with the basalts, while in Trotternish a few mugearites are also found. It must be emphasized that the olivine-basalts do not disappear even where mugearites become commonest, but alternate with them. The argument has already been advanced that the confinement of dykes of these less usual rock-types to the regions in which lavas of the same composition are found suggests that the lavas were erupted from fissures. There is also ample similar evidence provided by the dykes of olivine-phyric basalts similar or identical to the typical basaltic lavas, though this evidence does not extend to the most impressive of the dykes, those now filled with allivalite. The exact role of the Cuillins centre while the basalts were being erupted, if indeed it existed at this stage, is unknown. The

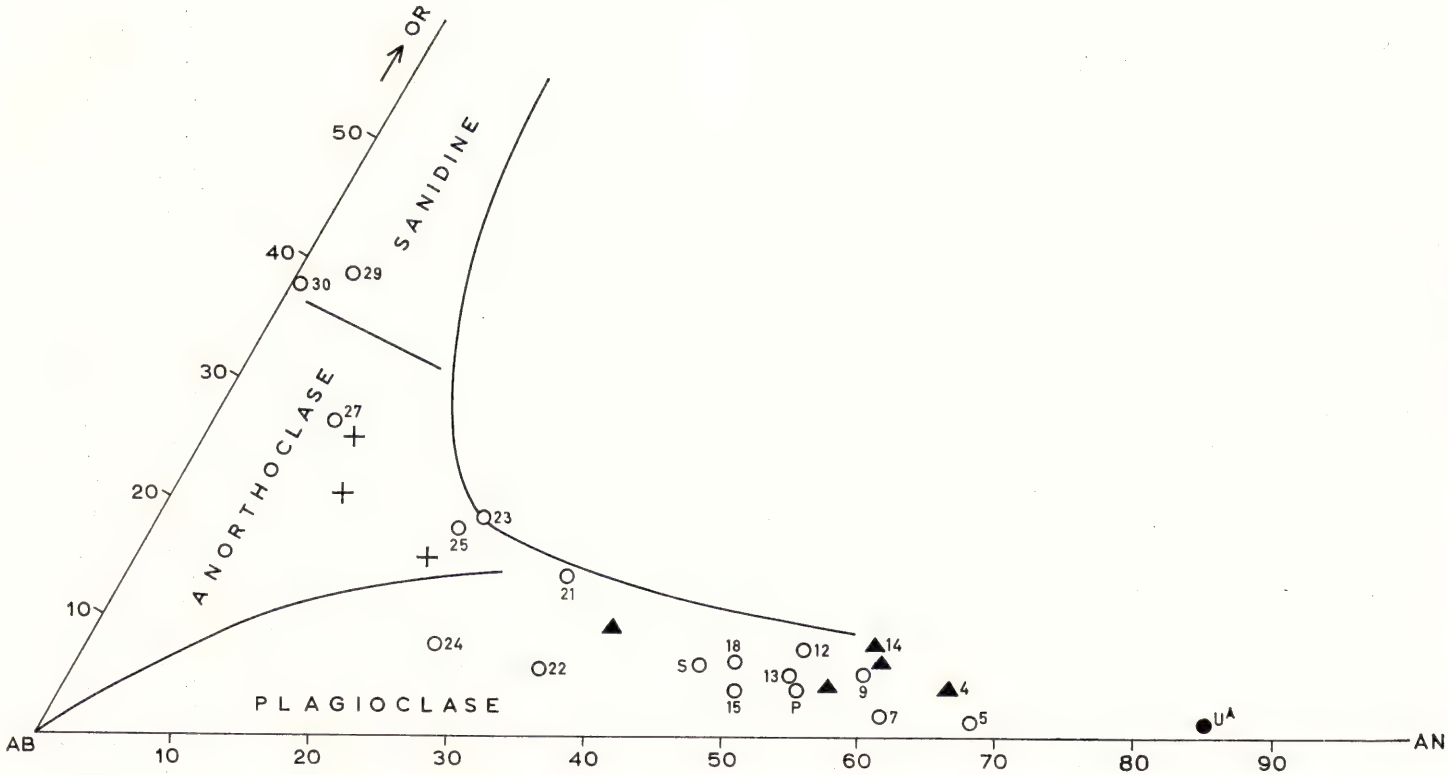


FIG. 16. *Plot of compositions of normative feldspars in Hebridean lavas and sills.*

Circles lavas; triangles, sills; black circle, dyke; crosses, feldspars from Druim na Criche mugearite, analysed by Muir and Tilley 1961. *P, tholeiitic pillow lava; S, normative feldspar in glass from palagonite tuff. Numbers correspond with those for Fig .17.* U^A, *allivalite dyke*

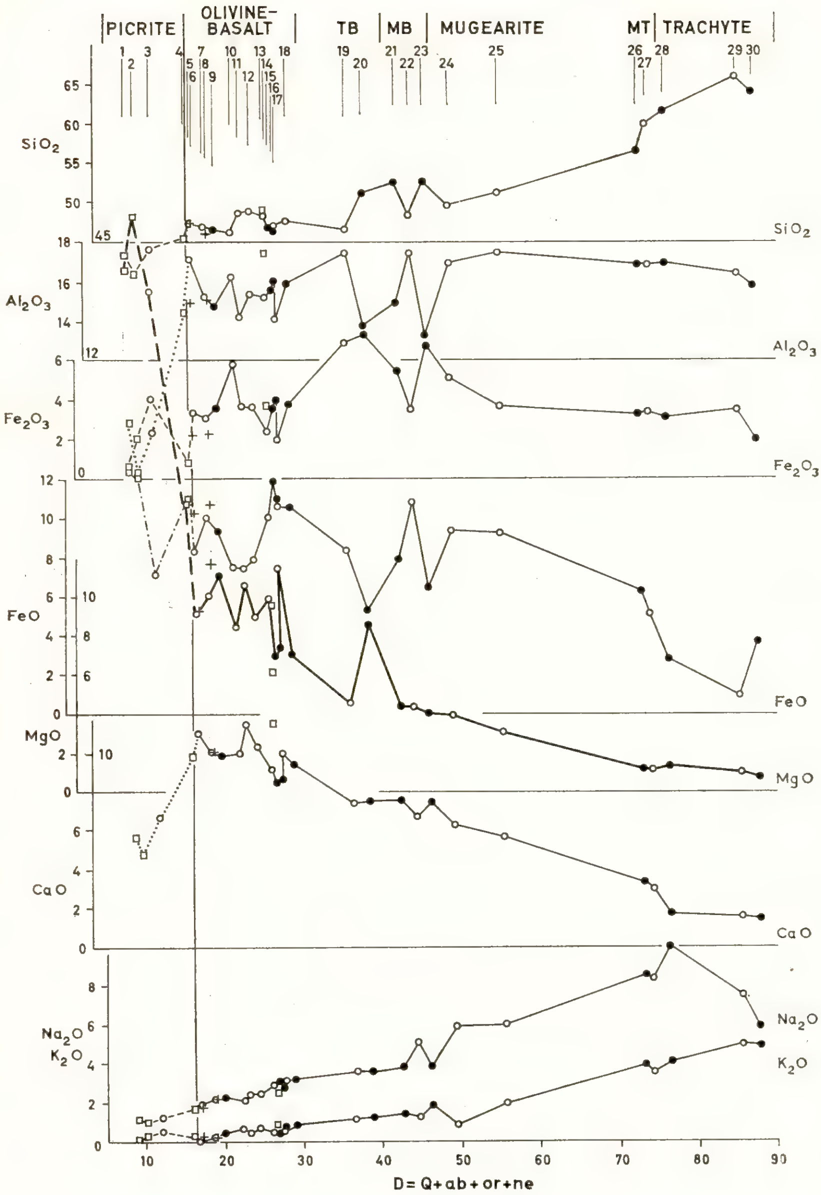


FIG. 17. *Variation diagram for the Alkaline Olivine-basalt lavas and minor intrusions. Black spots, Skye lavas; open circles, other Hebridean lavas; crosses, Antrim plateau basalts; open squares, North Skye and Shiant sills; TB trachybasalt MB mugearite-basalt; MT mugearite-trachyte. Picrite and picrite-basalt fall in a field limited by the line for D = 16·5 and are considered to be accumulative rocks*

lavas do not appear to thicken towards it, and only the rhyolites of Fionn Choire and Bruach na Firthe, south of the present area, appear to be definitely related to it. According to Harker (1904, p. 57) the stratigraphical position of these is in the midst of the basalt series, but their distribution is extremely local. The major intrusions of peridotite, gabbro and granite now exposed in the Cuillins centre are certainly later than the lava pile, but it is nevertheless possible that the main magma chambers were associated with the centre, and that the dykes were fed from there.

LIST OF CHEMICAL ANALYSES USED IN FIGS. 16 & 17.

1. Picrite, base of cliff S. of Garbh Eilean, Shiant; Walker 1930, p. 371.
2. Picrite, top of cliff W. of Camas Mor, Skye; Walker 1932, p. 246.
3. Picrite-basalt, An Carnach, Strathaird, Skye; Almond 1964.
4. Olivine-dolerite, 30 ft above beach, S. face of Garbh Eilean, Shiant; Walker 1930, p. 371.
5. Fine-grained basalt, 100 yd N.W. of Loch Cuil na Creig, Skye; King 1953, p. 365
6. Olivine-basalt, scarp E. of Dunmull Toberdornan Townland, 3 miles S.E. of Portrush, Northern Ireland; Patterson 1955, p. 103.
7. Ophitic basalt, 50 yd W. of Strollamus Quarry, Skye; King 1953, p. 365.
8. Olivine-basalt, scarp S. of County Road, Ballykeel Townland, 1¾ miles E.S.E. Portrush, N. Ireland; Patterson 1955, p. 103.
9. Basalt, E. side Rubha Dearg, 1 mile W. of Loch Aline, Morven; Bailey and others 1924, p. 15.
10. Olivine-dolerite, summit of Ben Lee N.W. of Loch Sligachan; Harker 1904, p. 248.
11. Olivine-basalt, flow 1, Ben Meabost, Skye; Almond 1960.
12. Olivine-basalt, near bridge over Allt Fionnfhiachd, Drynoch, Skye; Harker 1904, p. 31.
13. Olivine-basalt, Creag Mor, Skye; (p. 103).
14. Olivine-dolerite, Loch Mealt, near Waterfall, Skye; Walker 1932, p. 247.
15. Basalt, ⅓ mile N.N.E. Pennycross House, Mull; Bailey and others 1924, p. 15
16. Basalt, cliff 200 yd W. of Loch Eilean, Morven; Bailey and others 1924, p. 15.
17. Olivine-basalt, Achtalean 2¼ miles N.N.W. of Portree, Skye; Tilley and Muir 1962, p. 212.
18. Basalt, Orval, Rhum; Harker 1908, p. 57.
19. Olivine-dolerite, 500 yd N. of Tarn, Broc-bheinn, 4 miles N.N.W. of Sligachan, Skye; Harker 1904, p. 248.
20. Trachybasalt, An Carnach, Strathaird, Skye; Almond 1960.
21. Dolerite-mugearite, S. of Fionn-Chro, Rhum; Harker 1908, p. 130.
22. Mugearite-basalt, River Rha, above Uig, Skye; Muir and Tilley 1961, p. 190.
23. Doleritic mugearite, Eilean a'Bhaird, Canna; Harker 1908, p. 130.
24. Mugearite, cap of Hartaval, Skye; (p. 118).
25. Mugearite, Druim na Criche, near Mugeary, Skye; Muir and Tilley 1961, p. 190.
26. Mugearite (Benmoreite), 290 yd E. of Kinloch Hotel, Mull; Bailey and others 1924 p. 27.
27. Mugearite-trachyte (Benmorerite), Totardor, Skye; Muir and Tilley 1961, p. 190.
28. Trachyte, Ardnachross Vent, ¼ mile W. Rubha an t-Sean-Chaisteil, Mull; Bailey and others 1924, p. 27.
29. Trachyte, Ros a'Mheallain, Skye; (p. 118).
30. Trachyte, Vent, Braigh a'Choir' Mhoir, W. of Salen, Mull; Bailey and others 1924, p. 27.

The suite 'Plateau' or Hebridean basalt-mugearite-trachyte was considered by the authors of the Mull Memoir to form a related series and there are strong geographical and chemical reasons for this view. The chemical evidence shows that transitions exist between members of the suite, though this is not as complete as might be desired. It is conveniently summarized for Skye and for the whole Hebridean lava region on a variation diagram, in which the oxides (recalculated to eliminate water) are plotted against the 'differentiation index' of Thornton and Tuttle (1960). This index is the sum of quartz, orthoclase, albite and nepheline of the C.I.P.W. norm and since it represents crystallization from the petrogenic residual system SiO_2–$NaAlSiO_4$–$KAlSiO_4$, its magnitude increases with advancing differentiation. In the variation diagram no attempt has been made to smooth the curves; the lines join points in order of rising index values. The impression is thus conveyed of the progressive fall of MgO, FeO and CaO as the SiO_2, NaO_2 and K_2O rise, while demonstrating at the same time that considerable deviations from any possible average curve exist. While it cannot be denied, in the light of the international comparative studies of the results of rock analysis, that analytical errors may contribute to the irregularity of the curves, it is certain from the mineralogy of the rocks concerned that substantial variation in the oxides corresponding with any given index value exists. This is well illustrated by the cluster of basalts lying between index values 24 and 30. The same is evident from Wager's plots of albite ratios and normative plagioclase compositions against iron ratios (Wager 1956, p. 229).

The average Hebridean basalt lies in the region between index values 24 and 30, and it is significant that the normal olivine-dolerite of the Trotternish sills also falls here.

In Fig. 16 the normative compositions of the feldspars of those rocks in which normative nepheline does not appear are plotted in relation to the orthoclase-albite-anorthite triangle, to show the general trend of variation from the cluster of basalts on the calcic side of the centre of the plagioclase series, towards anorthoclase and sanidine in the mugearites and trachytes[1] (see also Muir and Tilley 1961, p. 201).

Causes of Variation. The physical chemistry of crystallizing silicate melts of basaltic composition, as revealed by experimental investigation of relevant systems, is such that the composition of the solid phases which separate differ to a marked extent from that of the liquid at all stages except the very latest. Ideally, therefore, the crystallization of basaltic magma is a fractional process, with the compositions of the crystals and the liquid changing progressively as the temperature falls. Providing, however, that fluid and crystals remain together until crystallization is complete, the composition of the rock produced will be the same as that of the parent magma; but it is unlikely that this ideal situation is ever attained, though under some circumstances it may be closely approached.

If, during the crystallization process, liquid and solid phases become separated, differentiated products will result. The earliest crystals to separate in quantity are magnesian olivines, which at normal pressure begin to crystallize at 1890°C. (Bowen and Schairer, 1935). Very calcic plagioclase follows below 1600°. The evidence from the layered series in Rhum, most recently described by G. M. Brown (1957) indicates that forsteritic olivine and bytownite-anorthite are denser than the basaltic magma, and under quiet conditions these minerals may settle to the bottom of a magma-chamber, producing 'cumulus' (Wager, Brown and Wadsworth, 1960). Meanwhile the liquid above will produce minerals less rich in MgO, FeO, CaO when it crystallizes. This mechanism for producing differentiated types has been familiar since the time of Harker (1908); it has been elaborated by many field and laboratory studies since then, too numerous to mention here.

---

[1] Three rocks, nos. 22, 24, 25, showing normative nepheline have also been plotted.

It should further be noted that a sudden change of temperature and pressure such as might take place when a magma is ejected from a subterranean chamber and extruded at the surface, must necessarily affect the compositions of the crystals able to separate.

It is clear that the Trotternish and Shiant sills offer good examples of the concentration of early-separated olivine to form picrite and picrodolerite, both by the phenomenon of sinking under the influence of gravity, and the activity of currents in the magma. It also seems probable that olivine cumulus may be carried in suspension by magma moving under pressure towards a point of escape, thus giving rise to picritic dykes and to basalts abnormally rich in this mineral. It is suggested that the two factors which contributed most to the considerable variation in olivine-content displayed by the Hebridean-type lavas were this one, and the factor of the stage at which eruption took place in relation to temperature change accompanying it.

Fig. 17 illustrates the chemistry of the accumulative rocks formed by the separation of olivine. These lie to the left of the line for D = 16·5, and in this area the curves for magnesia and ferrous oxide rise steeply, while ferric oxide, lime and alumina fall. Some of the variation in the olivine-basalt field is also doubtless due to removal of olivine at an early stage.

A rough test of the efficiency of crystallization differentiation to produce mugearite and trachyte from magma corresponding to average Hebridean-type basalt may be made by means of the graphical method known as the subtraction diagram. Table XIV gives average figures for the three rock-types, calculated from the analyses used in constructing Fig. 17.

TABLE XIV

AVERAGE HEBRIDEAN BASALT, MUGEARITE AND TRACHYTE

	Basalt	*Mugearite*	*Trachyte*
SiO_2	47·2	51·2	63·9
Al_2O_3	15·5	17·6	16·3
Fe_2O_3	3·2	4·9	2·9
FeO	9·9	7·5	2·4
MgO	9·0	2·8	0·9
CaO	9·4	4·9	1·5
Na_2O	2·7	6·4	6·4
K_2O	0·5	1·7	4·8
TiO_2	2·2	2·3	0·6
P_2O_5	0·2	0·5	0·3
MnO	0·2	0·2	—

Table XV gives the compositions and C.I.P.W. norms of the differentiate which must be removed from average basalt to yield average mugearite (1); from average basalt to yield average trachyte (2); and from average mugearite to yield average trachyte (3), together with the percentage-weight of differentiate to be removed[1]. It is immediately apparent that the fractions removed to form both mugearite and trachyte would be rocks such as are found as major intrusives in the Hebridean province—the first would be a eucrite, the second a gabbro—the fraction to give the transition mugearite to trachyte is not at all a likely composition and may be discarded.

One other possibility is perhaps worth considering. This is the addition, for example by assimilation, of foreign material to the magma. This can be examined by means of addition diagrams. The results for basalt to mugearite, and for mugearite to trachyte are given in Table XVI, together with norms.

TABLE XV

CALCULATED COMPOSITIONS OF SUBTRACTED DIFFERENTIATES

Composition	(1) *Basalt to Mugearite*	(2) *Basalt to Trachyte*	(3) *Mugearite to Trachyte*
SiO_2	45·5	45·3	44·6
Al_2O_3	14·6	15·4	18·3
Fe_2O_3	2·4	3·2	6·0
FeO	10·9	10·7	10·2
MgO	11·6	9·9	3·8
CaO	11·3	10·3	6·6
Na_2O	1·2	2·3	6·4
K_2O	—	—	—
TiO_2	2·2	2·5	3·2
P_2O_5	0·1	0·2	0·2
MnO	0·2	0·2	0·2
Percentage Removed	70	89	66
Norm			
ab	10·0	19·4	34·1
an	34·5	31·8	21·1
ne	—	—	10·8
di wo	8·7	7·8	3·5
di en	5·4	4·7	1·7
di fs	2·8	2·6	1·7
hy en	11·6	4·4	5·5
hy of	5·8	2·4	5·6
ol fo	8·4	11·0	8·8
ol fa	4·7	6·3	6·1
mt	3·5	4·6	1·3
il	4·3	4·7	
ap	0·3	0·3	
Normative Feldspar	An_{78}	An_{62}	

---

[1] The silica percentage is taken at the point where K_2O reaches the zero line in each case. In the addition calculations, the percentage at the point where MgO reaches zero is taken in the first, and where TiO_2 reaches zero in the second.

TABLE XVI

Calculated Assimilation by Mugearite and Trachyte

Composition	*Basalt to Mugearite*	*Mugearite to Trachyte*	*Syenite, Eilean Mhuire Shiant*
SiO_2	53·0	68·7	
Al_2O_3	18·5	15·6	
Fe_2O_3	5·7	2·2	
FeO	6·5	0·5	
MgO	—	0·2	
CaO	2·9	0·2	
Na_2O	8·1	6·4	
K_2O	2·2	5·9	
TiO_2	2·3	—	
P_2O_5	0·6	0·2	
MnO	0·2	—	
Percentage Added	69	73	

Norm

Q	—	10·0	—
or	12·8	35·0	25·6
ab	51·8	47·7	49·8
an	7·5	—	—
ne	9·1	—	4·0
ac	—	5·6	5·1
di wo	1·5	0·1	6·2
di en	—	0·05	
di fs	1·7	0·05	
ol fo	—	0·3	—
ol fa	1·6	0·4	—
mt	8·4	0·5	4·6
il	4·3	—	0·9
ap	1·3	0·3	1·0

Neither result is encouraging, though the material to be added to mugearite to produce trachyte is a possible rock composition, that of a quartz-syenite. It is not greatly different from an acid segregation found within the 60-ft thick syenite forming a centre to the Upper Dolerite of Eilean Mhuire, in the Shiant Islands (Walker 1930, p. 383 *et. seq.*), the origin of which is attributed to auto-intrusion of residual magma. It might thus be claimed that it is just possible for large bodies of rock of the required composition to exist, but it remains doubtful whether such large volumes could possibly be assimilated.

On the whole, therefore, the calculations support the view that mugearite and trachyte could be produced from basaltic magma by normal processes of fractional crystallization and separation of solid phases. It is suggested that mugearite is perhaps not an intermediate stage in the generation of trachyte; and it seems right to conclude that the acquisition of foreign material by the magma is a less attractive hypothesis than crystallization differentiation.

The average composition upon which the calculations discussed above have been based must nevertheless be viewed with some suspicion, for few of the

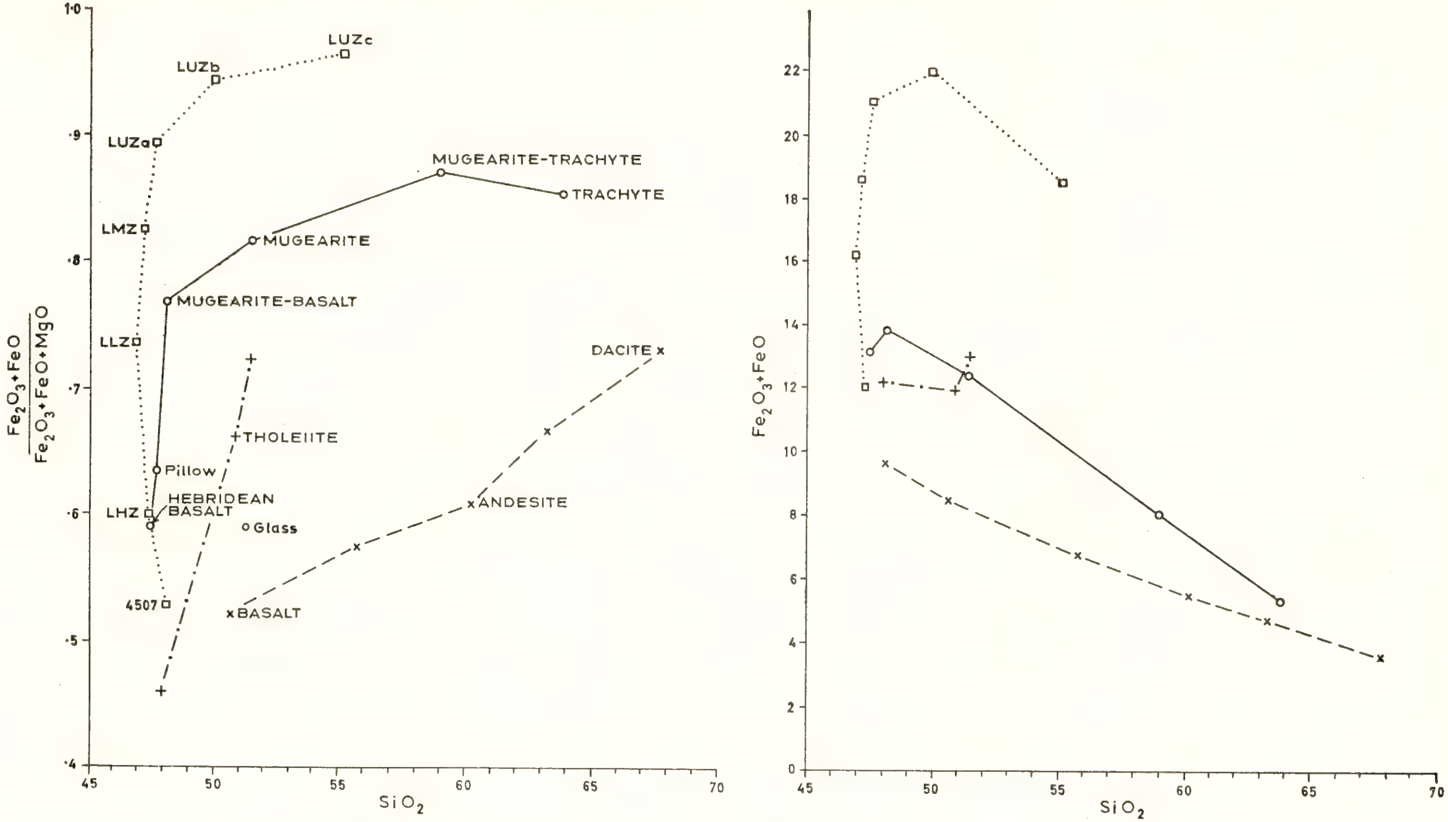


FIG. 18. *Plots of iron-oxide-magnesia ratio and iron oxide-content against silica.*
Dotted line, Skaergaard liquids (Wager 1960); full line, Hebridean alkaline olivine-basalt suite; dot-dash, average tholeiites (Nockolds 1954); dashes, Cascade volcanics (Osborn 1959)

analyses upon which they are based are of rocks in which the pyrogenic minerals are completely fresh. Tilley and Muir (1962) have pointed out that fresh basalts derived from the Hebridean magma type should not show significant amounts of hypersthene in the norm, and they cite the olivine-basalt of Achtalean (Table VI, No. IX) as an example. The fact that hypersthene appears in the norms of nearly all the analyses used to derive the figures for average basalt in Table XIV is the result of hydration and oxidation of olivine accompanied by selective leaching. While it must be agreed that the average lacks the validity of that obtained from the fresher alkali basalts of Hawaii, it is hardly to be expected that, if a suitable number of fresh basalts from the Hebrides can be found and analysed, the conclusions stated above about the relative importance of fractional crystallization and assimilation will be materially altered.

Role of Volatiles. So far no attention has been paid to the roles of the volatile and gas phases in the differentiation of the alkaline basaltic magmas. Yet sills, lavas and dykes alike reveal that water vapour, fluorine, carbon dioxide and other volatile phases were active, at least during the later stages of crystallization of each rock mass. To them the special crinanitic and teschenitic types in the sills are to be attributed, but these are only concentrated manifestations of processes from which few of the igneous rocks entirely escaped. To the fluids concentrated as crystallization proceeded are to be ascribed the zeolites and chlorite which occupy interstitial spaces in the feldspar mesh, which have in some cases partially replaced the feldspars and other minerals, and which have filled the amygdales. Combined water, held in these OH-bearing minerals, is not an accident but a characteristic constituent of the North Skye igneous rocks; and its effect was felt in many cases before the completion of the main crystallization of the rocks, as well as at later stages.

In a contribution which may well prove to be of fundamental importance for petrology, Osborn (1959) has shown, on the basis of a consideration of equilibria in the system FeO-Fe_2O_3-SiO_2 that crystallization may follow very different paths according to whether (i) the total composition of the system remains constant, or (ii) the partial pressure of oxygen is maintained at a constant level. He extends these considerations to the system embracing MgO, and to natural basalts and their associates, and suggests that alternative (i) leads to enrichment of iron in the liquid during fractional crystallization, such as Wager and Deer (1939) proved for the Skaergaard intrusion. Alternative (ii) can only be sustained if there is evolution and loss of gas, leading to decreasing iron oxide content and increasing silica in the liquid. In Fig. 18 the trend of the Iron oxide/iron oxide plus magnesia ratio is plotted against SiO_2 percentage to ascertain the relationship of the present alkaline basaltic series to Osborn's alternative paths. It emerges that it occupies a position intermediate between the closed system with extreme fractionation as represented by Skaergaard, the new figures for liquid compositions given by Wager (1960) being employed here, and the lava series from the Cascade Mountains cited by Osborn as characteristic of orogenic conditions, and approaching the open system situation. From olivine-basalt to mugearite, there is a sharp rise in the iron ratio with little change in silica, as in the main part of Skaergaard and in Nockolds's (1954) average tholeiites. But thereafter the curve for the Hebrides flattens off towards benmoreite and trachyte, suggesting that in the formation of these the conditions more nearly approached the situation where partial pressure of oxygen remained constant.

ALLIVALITIC AND FELDSPAR-PHYRIC ROCKS

It remains finally to consider the origin of the highly calcic plagioclase phenocrysts in certain of the dykes, and since the composition of the feldspar involved is the same, the remarkable allivalitic dykes of North Skye.

Dealing with the latter first, it is very improbable in the light of experimental studies that liquids of allivalite composition had a separate magmatic existence; certainly no satisfactory means is known by which such liquids could have been separated from basaltic magma. But, as already noted, the accumulation of very basic feldspars, separating as early crystal phases, is well authenticated from the allivalites of Rhum. Brown (1957) attributed the layered series to bottom accumulation of crystals, perhaps associated with sorting by currents and with occasional release of volatiles.

It is here suggested that the allivalite dykes represent portions of a bytownite-anorthite cumulus (as in Rhum but with less abundant olivine, clinopyroxene and titanomagnetite) which became mobilised and squeezed into dyke fissures. The mush of large feldspars appears to have been lubricated by basaltic liquid as attested by the presence of a little inter-crystal dolerite or basalt in some dykes (p. 156).

It is also tempting to ascribe the anorthite phenocrysts in the feldspar-phyric dykes to the break-up of cumulates of feldspar by intruding magmas of various compositions. It must be admitted, however, that the phenocrysts could have crystallized from the dyke magmas before intrusion. For example, magma of the average Hebridean-type composition corresponds in available Na_2O and CaO content to plagioclase of composition An_{58} but the corresponding solidus position is An_{85} and this will therefore be the anorthite-content of the first-formed crystals. The very calcic plagioclases could have crystallized from the dyke magmas in at least some cases; but if they did, the striking break in zoning which they often show must be attributed to the change of temperature upon intrusions into the dyke fissure. It is appropriate to add that the phenocrysts of the big-feldspar mugearite lavas (An_{66}) would also represent the appropriate composition to be expected when average mugearite magma began to crystallize.

There is no evidence that cumulates rich in calcic plagioclase were ever re-fused in the present area. Had this occured, magmas capable of producing high-alumina basalts in the sense of Kuno (1960) would have resulted. But as Kuno's fig. 10 shows, such rocks are not known from the Brito-Arctic region except in the chilled margin of the Skaergaard intrusion, East Greenland. During the present investigation, no aphyric high-alumina rocks have been disclosed.

SUMMARY

It is possible that tholeiitic magma was available at the beginning of volcanic activity in North Skye, and again when the late dykes were intruded. But the igneous events recorded in this part of the Island are mainly concerned with the extrusion and intrusion of alkaline basaltic magma, and with its differentiation during crystallization, to yield ultrabasics (picrite, allivalite) and the mugearite-trachyte series. It is possible that the escape of a gas phase may have exerted a decisive influence in the formation of the latter series.

No inference as to the ultimate primary magma—if there was a single one—seems appropriate from this limited study.

REFERENCES

ALMOND, D. A. 1964. Metamorphism of Tertiary lavas in Straithaird, Skye. *Trans. Roy. Soc. Edin.*, **65**, 413-34.

BAILEY, E. B., CLOUGH, C. T., WRIGHT, W. B., RICHEY, J. E. and WILSON, G. V. 1924. Tertiary and post-Tertiary Geology of Mull, Loch Aline and Oban. *Mem. Geol. Surv.*

BOWEN, N. L. and SCHAIRER, J. F. 1935. The system MgO-FeO-SiO. *Amer. J. Sci.* (5), **29**, 151-211.

BROWN, G. M. 1957. The layered ultrabasic rocks of Rhum, Inner Hebrides. *Phil. Trans. Roy. Soc., B*, **240**, 3-52.

HARKER, A. 1904. The Tertiary Igneous Rocks of Skye. *Mem. Geol. Surv.*

—— 1908. The Geology of the Small Isles of Inverness-shire. *Mem. Geol. Surv.*

KING, B. C. 1953. Structure and igneous activity in the Creag Strollamus area of Skye. *Trans. Roy. Soc. Edin.*, **62**, 358-401.

KUNO, H. 1960. High-alumina Basalt. *J. Petrology*, **1**, 121-45.

MUIR, I. D. and TILLEY, C. E. 1961. Mugearites and their place in igneous rock series. *J. Geol.*, **69**, 186-203.

NOCKOLDS S. R. 1954. Average Chemical compositions of some igneous rocks. *Bull. Geol. Soc. Amer.*, **66**, 1007-32.

OSBORN, F. F. 1959. Role of oxygen pressure in the crystallization and differentiation of basaltic magma. *Amer. J. Sci.*, **257**, 609-47.

PATTERSON, E. M. 1955. The Tertiary lava succession in the northern part of the Antrim Plateau. *Proc. Roy. Irish Acad.*, **57**, 79-122.

THORNTON, C. P. and TUTTLE, O. F. 1960. Chemistry of igneous rocks. I. Differentiation Index. *Amer. J. Sci.*, **258**, 664-84.

TILLEY, C. E. and MUIR, I. D. 1962. The Hebridean Plateau Magma Type. *Trans. Edin. Geol. Soc.*, **19**, 208-15.

WAGER, L. R. 1956. A chemical definition of fractionation stages as a basis for comparison of Hawaiian, Hebridean and other basic lavas. *Acta Geochimica*, **9**, 217-48.

—— 1960. The major element variation of the layered series of the Skaergaard intrusion and a re-estimation of the average composition of the hidden layered series and of the successive residual magmas. *J. Petrology*, **1**, 364-98.

—— and DEER, W. A. 1939. Geological investigations in East Greenland. Part III. The petrology of the Skaergaard Intrusion, Kangerdlugssuaq. *Medd. Grønland*, **105**, 1-351.

—— BROWN, G. M. and WADSWORTH, W. J. 1960. Types of igneous cumulates. *J. Petrology*, **1**, 73-85.

WALKER, F. 1930. The Geology of the Shiant Isles (Hebrides). *Quart. J. Geol. Soc.* **86**, 355-94.

Chapter XI

TECTONIC HISTORY

PRE-TRIASSIC MOVEMENTS

IN NORTHERN Skye no pre-Triassic rocks are exposed so that the structure of the basement on which these and later deposits rest must be inferred from what can be seen in Southern Skye.

The earliest earth-movements which can be detected are those which affected the Lewisian rocks prior to the deposition of the Torridonian Sandstone. It is evident that there were at least two periods of movement, since an earlier foliation with north-north-east and north-east axis was in existence before the intrusion of the basic and ultra basic dykes which are themselves foliated at right angles to this direction, i.e. north-north-west or north-west.

The presence of crush lines running east and west may indicate a still later period of movement.

The Torridonian appears to have been laid down as a series of torrential deposits on an almost peneplaned surface deriving in the first instance most of its material from local sources. In Skye these are epidotic grits and conglomerates, best exposed in Loch na Dal in Sleat. The Torridonian sandstones in many places show excellent examples of graded, current and slump bedding, the shales, rain-pitting and sun-cracks.

The Cambrian basal quartzite, originally a coarse, current bedded sandstone everywhere rests on an only slightly undulating surface of Torridonian which had a gentle north-easterly dip at the time the quartzite was deposited.

Lewisian, Torridonian and Cambrian were all involved in the subsequent Caledonian movements which in the first instance must have affected these rocks at considerable depth as they resulted in a huge complex recumbent fold with its axis running north-north-east (Bailey 1939).

Considerably later these piled up masses were cut by thrusts as a result of pressure from the south-east. It is possible that the whole of the Cambrian and Torridonian rocks in Skye lie within a thrust belt. (Clough *in* Peach and others 1910, p. 8).

The zone of flinty crush and mylonite which skirts the eastern coasts of the Outer Hebrides overlies a thrust which is generally presumed to be pre-Torridonian in age, because of the fact that above it, near Stornoway, is exposed a conglomerate with lenticular layers of soft, chocolate-coloured sandstone cropping out over an area of ten square miles and which is at least 9000 ft thick.

Jehu and Craig (1934, p. 867) regarded these conglomerates as Torridonian, but they differ in several respects from the Torridonian conglomerates of Skye and the mainland. Boulders in them include sheared gneiss and are all of local origin as is usual in the Triassic conglomerates whereas in Skye the Torridonian conglomerates include rocks of unknown origin, mainly vein quartz, chert and jasper. The Stornoway conglomerate is relatively uncompacted and the feldspars are highly decomposed, whereas in Skye the feldspars of the Torridonian are remarkably fresh and are chiefly microcline, which is not generally abundant in the Lewisian, and the rock is hard.

Stevens (1914, p. 59) therefore regarded the Stornoway deposit as Triassic in age, which if correct, means that the Stornoway Thrust could be another of the Caledonian group with which it compares in dip and strike. It may in fact be the earliest and deepest of the Caledonian thrusts and between it and the latest and highest, the Moine Thrust, are included all the Torridonian and Cambrian rocks of Skye.

Some isoclinal folding and regional tilting appears to have gone on during the period of thrusting, so that the two branches of the Kishorn Thrust in the area around Ord in Sleat appear to intersect and both are folded by a fold running almost north and south—the Ord Monocline.

The thrust belt is bounded on the east by the Moine Thrust which brought forward Lewisian and Moine on to what is now the island of Skye. The slice of 'Moine' lying west of the Moine Thrust in Sleat rests on the Tarskavaig Thrust and it is not yet certain whether these rocks are true Moine brought forward from below the Moine Thrust or whether they are in fact altered Torridonian.

Since there are no representatives of Silurian, Devonian, Carboniferous or Permian strata in Skye it is not known whether the area was involved in any earth-movements during these periods.

Post-Triassic, Pre-Tertiary Movements

Whatever the later Palaeozoic history of Skye, the result was a somewhat irregular surface on which Triassic conglomerates were irregularly deposited. They consist largely of material derived from the underlying rocks and were probably laid down in inland lakes.

Thin and patchy deposits of limestone, sandstone and calcareous grit of Rhaetic age form passage beds between the Trias and the Lias. The formation of the elliptical basin between the mainland and the Outer Hebrides in which the Jurassic strata were laid down was a gradual process many times interrupted. Sandstones with quartz pebble conglomerates, but no Torridonian Sandstone, in the lower beds of the Lias suggest that the Torridonian outcrop was now submerged and the sedimentary material was being derived from the Lewisian and Moine. Nevertheless, that the sea remained shallow is evidenced by a white sandstone with rootlets seen east of Ardnish.

The predominantly sandy strata of the Broadford Beds are succeeded by the micaceous shales, the Pabba Shales. A slight rejuvenescence of uplift, indicated by the Middle Lias sandstones, was followed by a quiescent period during which the ferruginous shales and limestones of the Upper Lias were formed. A considerable elevation of the hinterland brought an abrupt close to Liassic sedimentation and the basin became flooded with sandy deposits. These formed the calcareous sandstone of the Inferior Oolite. Sedimentation appears to have been rapid since the fossils are in general widely disseminated and scarce. Current and slump-bedding are common features and the calcium carbonate content was high enough to form large concretions or doggers. The down-warping of the basin, however, was unable to keep pace with the amount of sediment passed into it so that at the top of the Inferior Oolite the sandstones show evidence of shallow and perhaps fresh-water conditions in that they contain seams of quartz pebbles and plant debris.

In the Great Estuarine Series we have evidence that the whole area was at times elevated above sea-level without, however, essentially affecting the sedimentation pattern. The earliest deposits, the '*Estheria*' Shales consist of calcareous muds, often finely laminated and clearly representing not only extremely slow deposition, (fossils are usually found as layers of compressed shells) but also numerous alternations between marine and freshwater or brackish conditions. There are algal beds and layers of marine ostracods, numerous layers of '*Estheria*', crushed *Neomiodon* and *Bathonella*. The Calcareous Sandstone which follows consists of a number of cycles each unit comprising a calcareous sandstone with doggers and sandy shales and limestones, virtually a repetition of Inferior Oolite-type sedimentation but in a non-marine environment. It would seem that at this time the basin was bisected by a north-easterly trending ridge of Torridonian Sandstone crossing more or less where the Cuillin Hills now are. This ridge may not have risen above sea-level but does appear to have effectively cut off much of the coarse sediment from the southern and smaller half of the basin. The Great Estuarine Series is much thinner in Strathaird than in Trotternish and the thinning is almost entirely confined to the sandstone of each cycle.

A gradual regional down-warp brought to an end this non-marine phase and though the Callovian sediments were coarse, by Oxford Clay times the basin was again thoroughly marine and sedimentation slow. Dark blue shales with calcareous ribs were uniformly deposited throughout Oxford Clay, Corallian and Kimmeridge times, the changing ammonite fauna affording the only means of distinguishing the deposits from one another.

The events which followed into Cretaceous times can only be guessed. A few feet of grit, sandstone and limestone with chert and Upper Cretaceous fossils are all that remain. Much may have been removed by subsequent erosion but the nature of these deposits suggest that in Skye at least, the end of the Jurassic Period was marked by uplift and that Cretaceous sediments were very limited in their extent and amount.

Late Cretaceous or early Tertiary earth-movements appear to have been limited to gentle folding and large scale faulting. A series of small folds with their axes running north-east were formed *en echelon*. The most northerly is a small anticline a little south of Gearran Island with, almost due south of it, a syncline in Lub Score. An anticlinal axis runs from Kilmaluag south-west across Loch Snizort to An Ceannaich on the north side of Oisgill Bay.

Owing to lack of exposures the Quirang Syncline cannot be traced south-west of Uig Bay nor can the Beinn Edra Anticline south-east of it be seen south of Kingsburgh. Still farther to the south-east a syncline at Bearreraig Bay is hidden beneath the lavas as is the Portree Anticline. These are all small folds affecting only the Jurassic rocks and somewhat obscured by the Tertiary folding.

The major tectonic feature of this late Cretaceous epoch is the Camasunary Fault, which has a downthrow of at least 1000 ft to the south-east. In Raasay, where it was first recognized by Judd, the fault crosses from North Scapadal to Loch an Rathaid, throwing Inferior Oolite and Great Estuarine Series against Torridonian. North-eastwards it perhaps runs north-north-east parallel to the east coast of Rona where recent Admiralty soundings have indicated a deep channel. South-westwards the fault cannot be traced in the Braes of Skye but a fault of this magnitude is not likely to have died out in the short distance across the Narrows of Raasay. It is intersected by the Portree Fault but unless this is a tear fault, which it is apparently not in the usual meaning of the term, the only possible explanation is that it has been displaced by the emplacement of the Cuillin granite. In fact the Camasunary Fault in Straithaird is offset from the Raasay portion by exactly the width of the Glamaig, Marsco, Glas Bheinn Mhor intrusion. In Straithaird the fault can be traced from the south-eastern side of Camas Fhion-nairidh north-north-east not far east of the Abhuinn nan Leac until it passes below the Tertiary lavas of An Da Bheinn south-east of Blath Bheinn. But for this fault it is doubtful if any Jurassic rocks would have been now preserved in southern Skye.

Tertiary Movements

The surface on to which the Tertiary lavas were extruded was deeply weathered during the Eocene and reduced to a peneplain on which were fresh-water lakes in which the earliest Tertiary sediments (?Eocene) were laid down. The largest of these so far known lay in the neighbourhood of Portree and in it accumulated a considerable thickness of sandy sediment with plant remains prior to the effusion of the tuffs which marked the onset of volcanicity.

The collapse of the lava plateau and underlying sediments brought about by the extrusion of a vast amount of magma as lava flows and intruded as sills in the sediments resulted in the formation of a shallow depression criss-crossed by two sets of faults, a main group running north-west and a subsidiary set almost at right angles. Shallow folds, mainly developed in the north-west with axes trending north-west, broke up the Jurassic folds into a series of elliptical domes. This collapse was followed by the intrusion of many more basic dykes—often occupying a fault plane.

The gabbro laccolith had in all probability become emplaced at the time of the intrusion of the dolerite sills which appear to have originated at the same level. The doming of the lavas over the gabbro was probably due more to the collapse of the surrounding field round the rigid solidified igneous mass rather than to any upward thrust of the magma.

Later a granite plug thrust its way up on the east side of the gabbro apparently at the intersection of the Camasunary Fault and the Portree Fault. The displacement of the Camasunary Fault suggests that the country rock was literally forced apart to the full width of the intrusion.

The Beinn na Caillaich Granite, apparently later than the mass to the north, pushed the sediments to the south and east into an arcuate fold the core of which is occupied by a third intrusion, Beinn an Dubhaich Granite. If this interpretation is correct the Portree Fault must have acted as if it were a tear fault in the neighbourhood of the intrusions. The lateral shift of the Camasunary Fault is of the order of 5-6 miles, whereas to the south-east where much of the pressure was relieved by the arcuate folding, the Kishorn Thrust appears to have been displaced by less than half this amount, and if the Craig Skulamus Fault in the Strath with a displacement of about 1½ miles and the Ben Vokie Fault in Sleat displacing the Torridonian by about 1 mile and the Moine Thrust by less than ½ mile are continuations of the same transverse fault system, the movement is clearly dying out southwards. To the north of the granites there is no evidence that the Portree Fault is anything but a normal dislocation, with a downthrow to the west of about 1000 ft.

Westwards two parallel major faults, the Loch Greshornish Faults, together step down the lavas to the west about 1300 ft and are largely responsible for the preservation of the later mugearite and trachyte lava series. West of Ben Scudaig the Loch Bay Faults almost exactly compensate by an easterly downthrow of about 1400 ft.

No other of the numerous faults are of any great significance. The amount of throw is generally less than 500 ft and both the major north-westerly and the north-easterly cross-faults tend to compensate each other.

In the lava field structural details are almost impossible to elucidate owing to the fact that the recorded dips are depositional and not tectonic. The lava surfaces in general have an inclination which bears no relation to the true dip. For example in the Trotternish escarpment the lavas appear to have a westerly dip of 10-15 degrees whereas the surface on to which the lavas were extruded has a general westerly dip of only ¼ degree.

This gentle inclination of the whole island to the west is the latest earth-movement detected in the area and post-dates all the Tertiary volcanic phenomena.

Localized movements such as landslip and the thrust effects of the landslip sole on the underlying sediments are discussed in the following chapter.

REFERENCES

BAILEY, E. B. 1939. Caledonian Tectonics and Metamorphism in Skye. *Bull. Geol. Surv. Gt. Brit.*, No. 2, 46-62.

JEHU, T. J. and CRAIG, R. M. 1934. Geology of the Outer Hebrides. Part V—North Harris and Lewis. *Trans. Roy. Soc. Edin.*, **57**, 839-74.

PEACH, B. N., HORNE, J., WOODWARD, H. B., CLOUGH, C. T., HARKER, A. and WEDD, C. B. 1910. The Geology of Glenelg, Lochalsh and South-East part of Skye. *Mem. Geol. Surv.*

STEVENS, A. 1914. Notes on the Geology of the Stornoway District of Lewis. *Trans. Geol. Soc. Glasgow*, **15**, 51-63.

Chapter XII

QUATERNARY

After the cessation of volcanic activity and before the onset of glaciation there appears to have been a period of intensive weathering. It was during this period too that extensive landslipping seems to have taken place. A sheltered pocket in Coire na Banachdich in the western Cuillins has escaped glacial erosion. Here the gabbro is weathered to a considerable depth which contrasts with its hard smooth and striated appearance elsewhere, indicative of negligible erosion since glaciation.

In northern Skye little of the material produced by this late-Tertiary weathering has escaped subsequent removal by ice. Evidence for this period of weathering lies chiefly in the dolerite dykes, many of which are decayed to a considerable depth.

Glaciation. The evidence of glaciation in Skye are best seen in the central and southern half of the island where the hard gabbro of the Cuillins, the quartzite of the Cambrian and the hard Torridonian sandstone show scratched and polished surfaces in abundance. In the north, evidence for glacier movement is carried largely by the dolerite sills and dykes and by the moulding of the Jurassic outcrops. The lavas which form the land surface over most of northern Skye rarely show much direct evidence of glacial erosion.

That glacial action has played an important role in the shaping of the present landscape of Skye is evident, but it is equally clear that the general configuration was determined by aqueous erosion during the latter part of the Tertiary period. The subject of glacial erosion will be dealt with more fully below but it is necessary to realise at this point that prior to the advent of glaciation the rocks had been deeply weathered and the major features of the topography were already in existence.

In the early part of the Pleistocene, before Skye was reached by ice from the mainland, a local glaciation must have developed. This resulted in the formation of an ice-cap in the Cuillin area from which glaciers radiated in all directions.

In the north, valley glaciers may have developed along the Trotternish ridge and in this respect it must be remembered that the névé field of The Storr-Quirang range prior to post-glacial landslipping (p. 6) would have had an area almost twice that of the present day. To the east of it there was the pre-glacial landslip (p. 6); to the west, valley glaciers flowed down to the sea. It is possible that smaller mountain groups like that of Healaval Bheag and Healaval Mhor in Duirinish and the Beinn Bhreac-Beinn na Caillich ridge in Sleat also gave rise to independent glacier systems.

That part of the mainland ice-sheet which impinged on Skye and Raasay was built up of five major glaciers (Fig. 19). In the south, ice from Loch Hourn, Glenelg and Loch Alsh, moved westwards and over-rode Sleat. Beinn na Caillich (2403 ft), Ben Aslak (1984 ft) and Beinn na Seamraig (1839 ft), all Torridonian

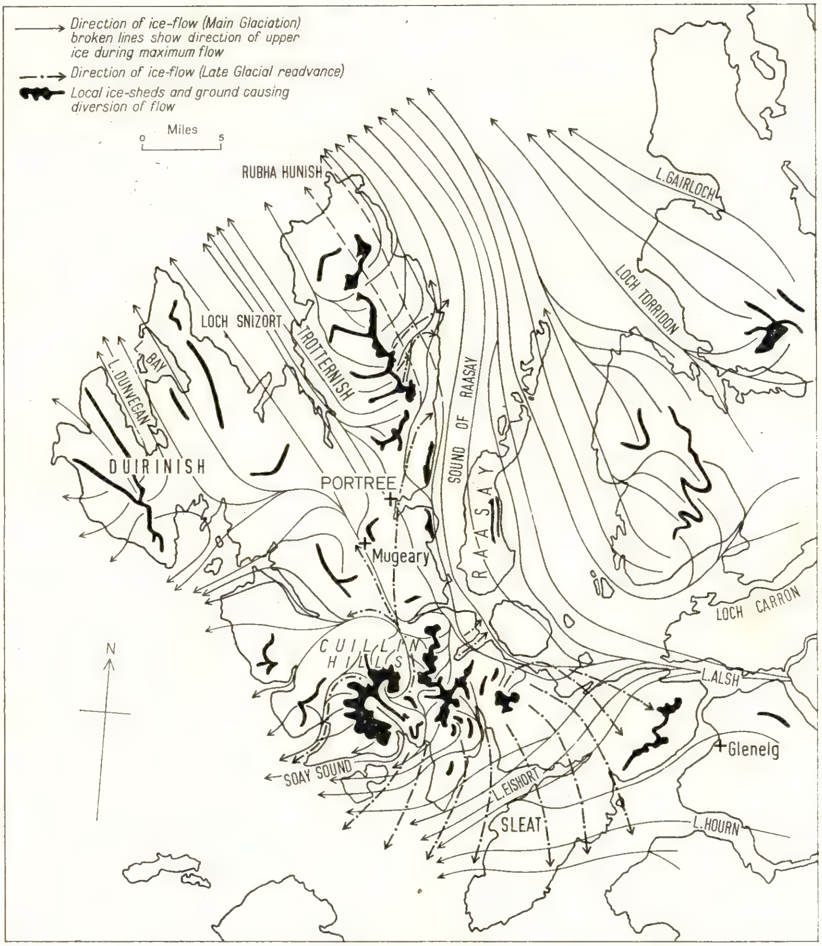

Direction of ice-flow (Main Glaciation) broken lines show direction of upper ice during maximum flow
Direction of ice-flow (Late Glacial readvance)
Local ice-sheds and ground causing diversion of flow
Miles
0
5
N
RUBHA HUNISH
L. GAIRLOCH
LOCH SNIZORT
TROTTERNISH
LOCH TORRIDON
BAY
L. DUNVEGAN
SOUND OF RAASAY
DUIRINISH
PORTREE
RAASAY
Mugeary
LOCH CARRON
CUILLIN HILLS
L. ALSH
Glenelg
SOAY SOUND
L. EISHORT
SLEAT
L. HOURN

FIG. 19. *Sketch-map showing movement of ice and other glacial features in Skye*

hills, though later over-ridden, must have at first caused a slight diversion, but to the south of them the ice movement was almost due west and practically at right angles to the Cuillin glaciers which were diverted by the greater pressure of the Highland ice. The Loch Slapin ice was forced to travel across Strathaird and Soay whilst the Loch Scavaig ice moved down Soay Sound. There is no evidence that Highland ice extended so far north as Strathaird and Soay.

The Loch Alsh glacier was split by Beinn na Caillich (2403 ft) at Broadford, into a southern stream which travelled in a south-westerly direction to join the Glenelg glacier in Loch Eishort, and a northern stream which effectively dammed the north-easterly flowing Cuillin ice and was itself diverted to the north-west.

The distribution of erratics suggest that this Glenelg ice was forced to keep to a north-westerly direction by the pressure of the Cuillin ice from Sligachan at least as far as Mugeary, after which it turned again westwards only to meet ice from Macleod's Tables, against which it split to form a southern stream down the Bracadale valley and a northern travelling north-westwards down Loch Dunvegan and Loch Bay. There is no evidence that the area between Loch Bracadale and Loch Dunvegan was ever overridden by Highland ice. The eastern part of this north-westerly Glenelg glacier passed to the north of Cruachan Beinn a' Chearcaill (888 ft) and Ben Uigshader into Loch Snizort, joined by ice which came by way of Glen Varragill and by a stream diverted by Ben Lee (1456 ft) over the Braes, Ollach and Portree to Loch Snizort Beag.

Judging by the intense erosion which resulted, the eastern half of the Loch Alsh ice, joined as it was by ice from Loch Carron and further north by the Loch Torridon glacier, formed the thickest and most powerful of the ice-flows which affected Skye. With the possible exception of the Dun Caan ridge (maximum 1456 ft), Raasay was completely over-ridden. Much of the Inner Sound and the Sound of Raasay is over 50 fm deep so that, assuming the ice-sheet remained grounded, it is not likely to have been less than 1700 ft or much more than 2000 ft thick. Thus the bulk of the ice flow was diverted to the north by the eastern coast of Skye, which is a cliff made up of Jurassic sediments and Tertiary dolerite sills. In the south at Ben Tianavaig it is capped by lavas and reaches 1352 ft, north of Portree at Sithean Bhealaich Chumhaing it is 1286 ft and descends gradually to sea-level at Staffin. Behind this is a second barrier, the Trotternish lava scarp, much of which exceeds 2000 ft. Once free of the Cuillin ice therefore, the Loch Alsh–Loch Carron stream met a north-south barrier to its westerly progress which in places exceeded 2600 ft. Thus at Rubha na h'Airde Glaise the lower 1300 ft of ice could not have moved westwards. Some came ashore south of it and meeting the barrier of Beinn a'Chearcaill (1812 ft) was forced to continue northwards over Loch Fada and Loch Leathan and back to join the main stream at Tottrome. Even if the ice thrust against the Trotternish ridge reached a higher level than in the open Sound and even if at its maximum it over-rode the ridge at say 2500 ft, the greater bulk must still have been confined to the east of the Trotternish ridge with only the upper layers over-spilling through the bhealach into the Haultin, Lon Mor, Romesdal, Hinnisdal, Glen Uig and Rha valleys which lead westwards into Loch Snizort. It is notable that all the bhealachs between The Storr and Beinn Edra are at more or less the same level i.e. 1650 ft O.D. Since no evidence of northerly ice movement has been found above this level, it is thought that during most of the main glaciation the ice-level stood at about 1700 ft O.D. against the east of the scarp and thrust small piedmont glaciers through the gaps in the ridge into the western valleys.

This would mean that an ice stream passed south of The Storr, travelled northwards on the west of the scarp and joined the main stream again at Bealach Uige north of Beinn Edra. Thus the Storr-Beinn Edra ridge was for much of this time a nunatak. Charlesworth (1956, p. 874) in his account of the late glacial history of Northern Scotland came to a similar conclusion.

North of Meall nan Suireamach where the sea-cliff is low, the westward pressure of the Highland ice began to take effect and the ice-stream swung round to the north-west over the low ground between Kilmaluag and Duntulm. Here the full weight of the ice-sheet had its effects and deep grooves were cut like that between Kilmaluag Bay and Lub Stac nam Meann, reminiscent of those seen in Raasay.

Here in the north and again south of the Cuillins the ice-sheet may have extended as far as the Outer Hebrides but the resistance to westward flow offered

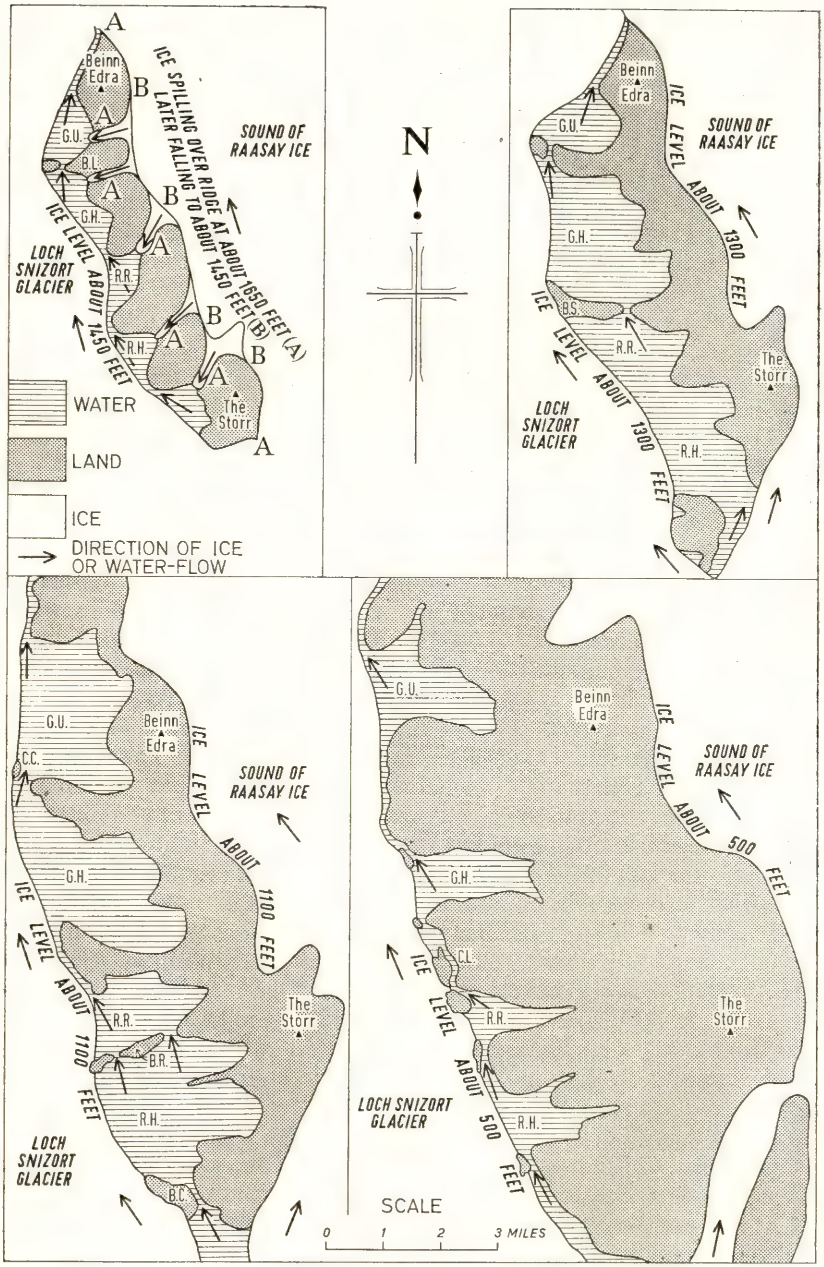

A
Beinn Edra
B
ICE SPILLING OVER RIDGE AT ABOUT 1650 FEET (A)
LATER FALLING TO ABOUT 1450 FEET (B)
SOUND OF RAASAY ICE
G.U.
B.L.
G.H.
R.R.
R.H.
The Storr
ICE LEVEL ABOUT 1450 FEET
LOCH SNIZORT GLACIER
WATER
LAND
ICE
DIRECTION OF ICE OR WATER-FLOW
N
ICE LEVEL ABOUT 1300 FEET
B.S.
ICE LEVEL ABOUT 1100 FEET
C.C.
B.R.
B.C.
ICE LEVEL ABOUT 500 FEET
C.L.
SCALE
0 1 2 3 MILES

FIG. 20. *Glacial retreat stages in Trotternish, Isle of Skye BC, Bealach a'Chaol-reidh; BL, Beinn an Laoigh; BR, Beinn an Righ; BS, Beinn a'Sga; CC, Creag Chragach; CL, Creag an Locha; GH, Glen Hinnisdal; GU, Glen Uig; RH, River Haultin; RR River Romesdal*

by most of Skye must have so reduced the pressure that it is unlikely that the ice margin extended far beyond the west coast.

Retreat of the Highland Ice. With cessation of the main glaciation the pressure of the Highland ice on Skye was relaxed and by stages the ice retreated from the island. Some evidence of these retreat stages is to be found on the west side of the Trotternish ridge. Four main pauses, designated the 1450-ft, 1300-ft 1100-ft and 500-ft stages, from the approximate levels of the ice edge of the Loch Snizort Glacier in Western Trotternish during the cutting of the glacial drainage channels, are shown in Fig. 20. Indications of a still higher stage at about 1650 ft, marked by the spilling over of ice on the main ridge from east to west, are indicated on the 1450-ft diagram. On the east side of this ridge landslipping seems to have occurred *pari passu* with the withdrawal of the stabilizing effect of the ice and all signs of retreat stages destroyed.

Whether the ridge was ever completely submerged or not (p. 179) there is on the western side evidence of a period of stasis at about 1450 ft (Fig. 20). As has already been suggested, the heights of the cols in this ridge are uniformly at about 1650 ft, which level is also believed to mark the maximum height (to within say 50 ft) of the ice-level on the eastern side. On the west, where the direct pressure of Highland ice was not felt, the ice probably stood at a lower level which may have been marked by the overflow channel of Beinn an Laoigh at 1450 ft. Ice or water was dammed in the Fuar, Iomhair and Chaiplin corries but in these it was confluent. The Beinn an Laoigh ridge however, formed a barrier to drainage towards the north and a channel was cut to allow access to Coire Amadal.

A second stage in the retreat is marked at about 1300 ft, (Fig. 20). By this time the ice-level on the eastern side had probably fallen below 1650 ft and the ice-lakes in the western corries cut off from their source of supply. With the western ice-stream at 1300 ft lakes were formed in the valleys the exits of which were still closed. The lake in Romesdal drained by way of two channels in the Beinn a'Sga ridge, both at about 1300 ft, into Hinnisdal and from thence by a channel in Beinn Fhuar (1300 ft) to Glen Uig.

Evidence for a pause at about 1100 ft is more complete (Fig. 20). A lake held up in Eskidal drained northwards through Bealach a'Chaol-reidh at about 1100 ft into the valleys of the River Haultin and Lon Mor and thence by way of two channels in the Beinn a'Chapuill-Beinn an Righ ridge, both at about 1050 ft, into Romesdal. Drainage appears to have been lateral into Hinnisdal, by this time containing a large body of water and from here one of the best examples of a drainage channel, i.e. that east of Creag Chargach at 950 ft, leads into Glen Uig. From here drainage was lateral into the Rha valley lake, from which water escaped northwards through a channel in Beinn a'Sga at 850 ft. This series of channels indicates a uniform thinning of the western glacier northwards from about 1100 ft at Portree to a little over 800 ft at the point where it joined the eastern glacier south and east of Duntulm.

Retreat next appears to have taken place more rapidly and except for one or two rather dubious channels at about 700 ft there is little evidence for another pause until the ice-level had dropped to about 550 ft, and then to 500 ft (Fig. 20). At the south-western end of the Haultin valley are channels at 550 and 500 ft and again between Romesdal and Hinnisdal at Creag an Locha and Creag Madragil. Between Hinnisdal and Glen Uig at Beinn Bheag only the higher channel is present whereas at Creag Moine, between Romesdal and Haultin valley, only the 500 ft channel is seen. The best developed of all is just west of Creag na Cuthaige at about 450 ft.

Evidence that the main flow of Highland ice east of the Trotternish ridge was standing at a higher level than that in the Chracaig valley and, by inference, that to the west of the ridge during at least one of the retreat stages is clearly shown by the terminal and lateral moraines of a short lobe of ice thrust westwards into the head of Lon Druiseach 3 miles N.N.E. of Portree. The Sound of Raasay ice must have been standing at a little over 1100 ft when it spilled through a gap in the cliff-top north of Sithean Bhealaich Chumhaing to form this small glacier.

Away from the Trotternish ridge evidence for the retreat stages is not easily found. Channels at about 950 ft are to be seen on the east side of Beinn na Greine, S.W. of Portree, at the 450-500 ft level east of the Vaternish ridge and east of the Healaval Mhor—Healaval Bheag massif.

One of the most interesting areas is that lying between Loch Harport ice on the west and the Sligachan—Mugeary ice on the east. This, at the 500 ft retreat stage, was apparently clear of ice and probably formed an area of tundra topography with numerous lakes and a complex series of drainage channels, here referred to as the Bracadale-Edinbain lake system (Fig. 21).

Late-Glacial Re-advance. Following the final decay of the main ice-sheet and a period of milder climate came a renewal of glacial conditions represented in Scotland by the development of valley glaciers.

In Skye a small ice-cap was re-established in the Cuillins together with a radial glacier system. The Trotternish ridge developed small glaciers on both slopes, those on the eastern side flowing for the most part over the landslip which had become established after the retreat of the main ice sheet (p. 190).

The Cuillin ice had two main outlets i.e. southwards into Loch Scavaig and northwards into Glen Sligachan. Subsidiary glaciers from Blaven and Beinn na Cailleach flowed down Loch Slapin and southwards across the Strath to Sleat. From Marsco, Beinn Dearg and Glamaig the flow was north-eastwards down Loch Ainort and north-westwards to join the main Cuillin ice from Glen Sligachan and so north down Glen Varragill and the Chracaig Valley to Bearreraig, and down Glenmore to Mugeary, whilst a westerly branch flowed down Glen Drynoch to Loch Harport. Four small glaciers combined on the western Cuillins to feed ice into Glen Brittle.

The Trotternish ridge appears to have nourished at least seven small glaciers. On the eastern side the Lealt glacier was fed from corries between Carn Liath and Sgurr Ruaidh, the Kilmartin glacier originated in Coire Cuither and probably became confluent in Staffin Bay with the Brogaig glacier from Druim na Coille. Probably also a small glacier originated in Coire Scamadal and flowed down the valley of Rigg Burn.

On the western slopes ice from The Storr and Beinn a'Chearcaill gathering ground became confluent in the Haultin river valley and flowed westwards into Loch Eyre. The Romesdal valley carried ice from Hartaval. Glen Hinnisdal, a magnificent example of a glaciated valley, was occupied by a glacier formed by three confluent streams from Coire Fuar, Coire Iomhair and Coire Chaiplin. In Glen Uig the topography is complicated by extensive landslip in the middle section of the valley but in the higher reaches shows typically glaciated features caused by ice from Coire Amadal and Bealach Uige.

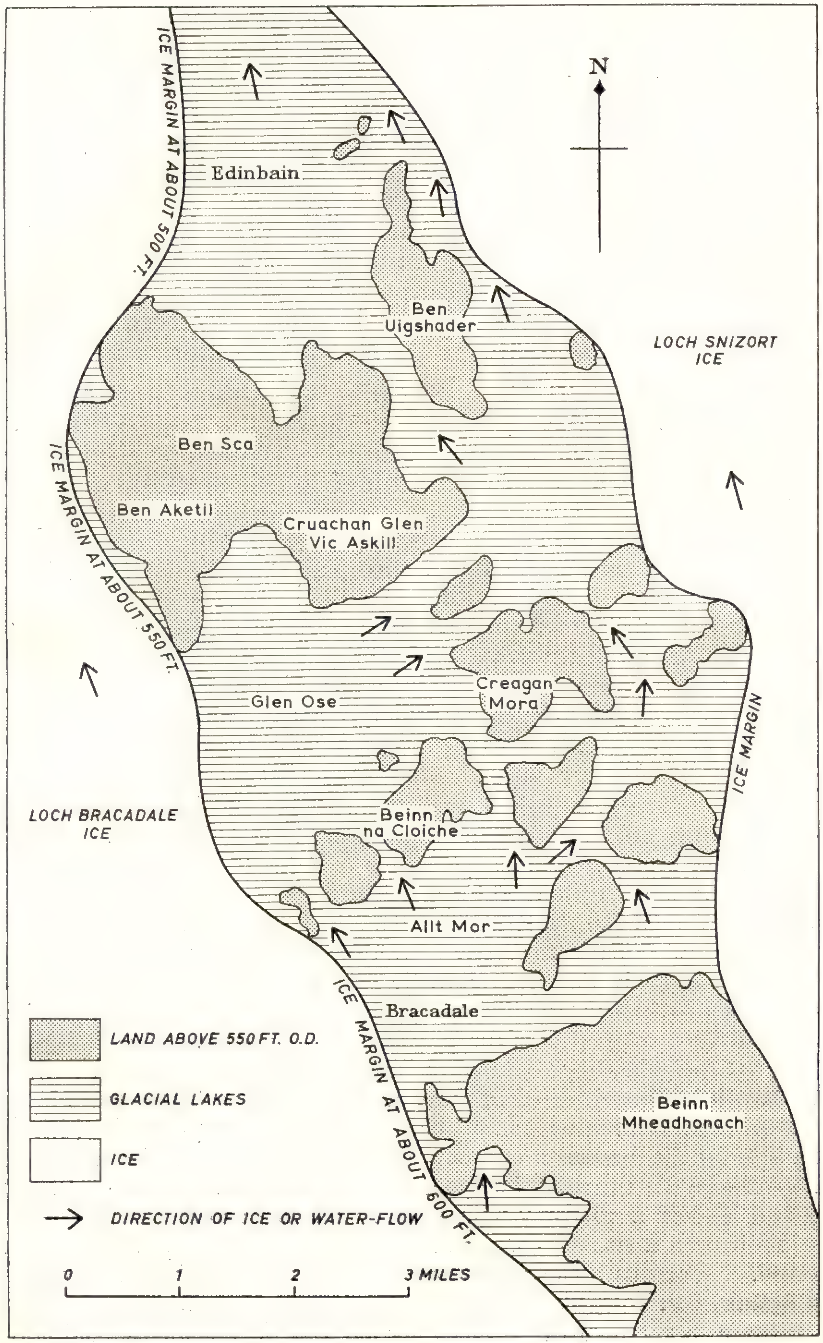


FIG. 21. *The Bracadale-Edinbain late-Glacial lake system at the 550-ft retreat stage*

Valley Glacier Retreat stages. In the valleys of three of the eastern glaciers a deeply cut gorge commences at the seaward end at about 200 ft, i.e. in the Rigg, Lealt and to a less extent in the Kilmartin Rivers and again less conspicuously in the western valleys. These may indicate the maximum extent of the glaciers, or, more likely, an early resting stage in their retreat.

Another break in the valley profile occurs between 400 and 500 ft, perhaps representing a later retreat stage. Certainly above this level the ice became stagnant and produced, on melting, typical hummocky moraine. Terminal moraines are very rare but the later stages of the Kilmartin glacier left both lateral and terminal moraines in the area round Loch Cuithir at about 600 ft.

The longer glaciers from the Cuillin ice-cap in Glen Varragill and Glenmore must have decayed more or less *in situ* leaving hummocky moraines along the whole length of both these valleys.

Glacial Erosion. The resistance offered by Skye to the westerly progress of the Highland ice-sheet led to the building up of enormous ice-pressures. Consequently glacial erosion on the eastern side of the Trotternish ridge was very considerable. Coming directly under the sole of the ice, Raasay was considerably and typically eroded. Deep parallel grooves were cut in the felsite sill which covered much of the area of the central and southern parts of that island. In Skye this type of erosion is only found where the full thickness of the Highland ice came to bear on the island, i.e. south of the Cuillins, especially in Sleat where the Torridonian rocks are deeply scoured and north of the Trotternish ridge between Flodigarry and Duntulm.

Along the whole of the east coast from Sligachan to Flodigarry the ice was moving northwards and bringing to bear very considerable lateral pressure on the coastal cliff and the lava-escarpment behind. Thus from Portree to Staffin the sea-cliff forms a gentle curve virtually unbroken by indentations or promontaries.

The less resistant Jurassic sediments have been cut back to form ledges whilst the harder dolerite sills stand as vertical faces. Wherever a prominence does break the even curve of the coast-line it is due to an outcrop of igneous rock—the Balmeanach promontary is a felsite sill, Holm Island, Rubha nam Brathairean, Rubha Garbhaig, Staffin Island, Eilean Flodigarry, Sgeir Eirin and The Aird are all dolerite sills. The re-entrants are all due to the presence of sediments—Tianavaig Bay is in Jurassic rocks and Palagonite Tuffs, Portree Bay is in Palagonite Tuffs, Staffin and Kilmaluag bays are in Jurassic sediments.

Inland the erosive effect of the ice was more spectacular. If, as is argued on p. 190 pre-Glacial landslips covered the low ground between Portree and Bearreraig Bay, it was entirely cleared away, as was that fronting the scarp between The Storr and Sron Vourlinn. Thus conditions were created which were favourable for the formation of a new landslip once the ice had retreated. The strath between Portree and Loch Snizort was one of the few places where Highland ice had a relatively uninterrupted passage across Skye to the west. Here, though on a smaller scale than in Raasay, longitudinal grooving can be observed. Numerous rock knobs show a north-north-westerly alignment, e.g. Dun Sgalair, Ben Tote, Skerinish Duns, Creag nam Meann.

Erosion by the re-advance valley glaciers was far less intense and nothing like the characteristic steep-sided U-shaped valleys of the Cuillins is to be found in northern Skye.

The valleys on the west of the Trotternish peninsula however, such as Glen

Uig, Hinnisdal and Romesdal have typical corries at their heads, below which they broaden rapidly into a wide flattened U-shape.

There are examples of typical semi-circular corries on the eastern scarp also like that west of Carn Liath, Coir 'an t-Seasgaich and Cuither, but in the tumbled masses of the landslip the valleys soon lose their regular glacial form.

Glacial Deposits. Boulder clay, though usually thin and stony, is widely distributed throughout Skye.

Occasionally however, in valleys such as Glen Varragill and the upper reaches of the River Rha, quite considerable thicknesses are to be found. In the upper part of the Lealt River 15 ft of blue boulder clay has been recorded and in the River Brogaig at Staffin, it is between 12 and 18 ft thick. The Abhainn nan Cnoc, north-east of Loch Cuither, and outside the landslip margin, runs in a gorge 30 ft deep in which can be seen two boulder clays separated by banded silts, in all about 25 ft thick.

Thin boulder clay was produced by some of the re-advance glaciers and in places must rest on boulder clays of the main glaciation, but it is only where they are separated by landslip that any distinction can be made between them (p. 193).

Erratic Boulders. Rocks foreign to Skye introduced by Highland ice are rare. The erratics found on the western side of the Cuillins are all local basalts, gabbros and granite. East of Sligachan, though granites predominate, there are some Moine and Torridonian boulders. This distribution supports the suggestion that the Cuillin ice-cap excluded mainland ice from its western side.

Boulders of Torridonian sandstone have been found in Loch Vatten and the Lampay Islands along the line where the western margin of the Loch Dunvegan glacier was in contact with the local ice from Healaval Bheag and Healaval Mohr.

Elsewhere the only erratics recorded are local igneous and sedimentary rocks. Some of these are very large, e.g. Clach Chraigisgean, a mile west of Balgown in Trotternish, is an enormous block of dolerite which must have been brought by the north-easterly ice-stream from a more southerly exposure of the sill on the ice-smoothed surface of which it now rests. In the Kilmaluag River, west of Druim Fada is a large mass of Kimmeridge clay which appears to have been moved a mile or so from the outcrop to the south-east.

Moraines. None of the morainic deposits seen in northern Skye can match in size and perfection of form those seen in the Cuillin area. Small lateral moraines are present in some of the valleys on the eastern side of the Trotternish ridge especially in the upper reaches of the Lealt River but terminal moraines are rare. West of Loch Cuither and at the head of Lon Druiseach are both lateral and terminal moraines but these are small.

By far the most common type of morainic deposit in northern Skye is 'hummocky drift' or 'kettle-moraine'. This, the characteristic deposit of stagnant ice is excellently developed in Glen Varragill, Glen Drynoch and Glen More. Hummocky moraine is also found in Glen Varkasaig, once occupied by a glacier from Healaval Bheag; in the strath between Portree and Loch Snizort Beag especially round Borve and Achacork; and in the valleys on the western slopes of the Trotternish ridge i.e. Lon Mor, Romesdal and Hinnisdal.

Sands and Gravels. Except for a small patch at Fasach in the Hamra River, Duirinish, sands and gravels have not been recorded.

Raised Beaches. There is abundant evidence in northern Skye for the previous existence of sea-levels higher than that of the present day. Since Tertiary times however, the coast of Skye must have been, as it now is, for the most part rocky and precipitous. Consequently the coastal features were mainly formed by erosion and not by deposition and do not indicate actual sea-level with any accuracy. Thus the oldest, the 100-ft Beach-level is marked by rock platforms at various levels between 75 and 90 ft O.D., the 50-ft Beach level by features at about 35 to 45 ft O.D. and the 25-ft level by platforms between 10 and 20 ft O.D. This lowest beach-level may fall within the limits of present beach development and is in places partly covered by more recent storm-beach.

At the present time deposition of beach material is taking place primarily in embayments and inlets such as the bays of Staffin, Lub Score, Uig, Portree, Ardmore and Dunvegan and it is in these same areas that deposits were formed at times of higher sea-levels. The 100-ft Beach deposits in Cairidh Ghlumaig (Lub Score) and near Monkstadt contain sea-worn shells as do the 25-ft Beach deposits in Loch Caroy between the mouth of Ose River and Ose Point (Loch Bracadale) but this is unusual.

The 50-ft sea-level is marked by a rock-ledge ⅓ mile S. of Cairidh nan Ob. Such features are not uncommon but it is difficult to identify them with any certainty since the basalts and dolerites which form so much of the coast of N. Skye are not marked by mollusc borings which in limestone country give an infallible and accurate datum line.

All three raised beaches are present and well seen on the south side of Staffin Bay, from Kilmaluag Bay westwards to Solitote, in Lub Score, Skeabost and Loch Bay. The highest beach-flat is the best developed and most extensive, covering a considerable area both at Stenscholl and Kilmaluag and probably extended southwards from Camas Mor almost to Totscore, an area later occupied by Loch Chaluim Chille.

The 50-ft Beach is usually found associated with the higher one and is not always clearly separable especially when, as is frequently the case, both are peat-covered. The lowest (25-ft) platform is only seen as narrow coastal strips except in places like Ardmore Bay in Vaternish, and Balmeanach Bay south of Portree, where the beach flat links a rocky island with the shore, and Isay Island in Loch Dunvegan where the whole island except for a small rock knob consists of 25-ft Beach-flat.

Landslip: Definition. So many varied phenomena have been described under the heading of landslip that some definition of what is, in this instance, meant by the term, is necessary. Only those movements which exhibit the following characteristics are here regarded as true landslip:

(i) In vertical section the glide-plane is a curved surface on which the overlying material moves downwards and outwards. A rotational element in this movement is an essential feature of landslipping.

(ii) In horizontal section the glide-plane is also a curved surface so that the inner margin of the slipped mass is always a curve.

Other related phenomena are:

(a) Rock Falls (including Scree) in which fragments of rock have broken away from the parent mass and fallen to a lower level. Characteristically, the individual blocks are orientated in a disorderly fashion and the whole has the form of a cone of talus.

(b) Rock-Slides in which masses of rock have slid along an inclined bedding plane away from the parent mass. Individual blocks tend to be inclined towards the direction of movement because of deceleration at the base.

(c) Creep, the material of which, usually already unconsolidated, moves by gravitational pull down an incline without the formation of a controlling glide-plane. As in landslip, but unlike rock-slides, the material is forced into ridges and hollows at right angles to the direction of movement.

The mechanics is, however, different from both in that the movement appears to consist of small asymmetric folds which become underthrust from behind.

Mechanics of Landslip. The basic principles affecting the formation of landslip are relatively simple. The essential requirements are a plastic or semi-plastic material capable of deformation by shear, sufficient load to overcome the internal resistance of the material to shear and a unilateral release of pressure allowing the development of shear-planes. The operational force is gravity.

The mechanics of landslipping have been investigated largely by civil engineers who are concerned with the practical problems involved. An empirical formula has been proposed—Coulomb's equation, primarily intended to apply to small scale slipping in embankments etc. But with certain reservations the general principle appears to apply to slip of any size (see Petterson 1955).

The basic assumption is that the form of the shear-plane is cylindrical and, therefore, the movement of the slipping mass is rotational. There is ample evidence for this in most landslips. The equation is:

$$\mu = \rho \tan \theta$$

where μ = shearing resistance per unit area
ρ = normal compressive stress
θ = angle of shearing resistance (angle of internal friction)

The glide plan is in fact a logarithmic spiral having the equation $r = r_0 \varepsilon \theta \tan O$ (see Terzaghi and Peck 1948) but the simpler equation above suffices for all practical purposes.

For clays, which are the most common contributing factor in landslip the equation should be written:

$$\mu = c + \rho \tan \theta \text{ where c is the cohesion.}$$

θ for clay is generally about 15°. The coefficient of friction in clay is largely dependent on the amount of included water which reduces the resistance to shear (see Skempton 1953).

Though this equation appears to apply reasonably well to the relatively simple case of a single slip it is clearly inadequate in the case of the larger compound slips in Skye.

These show that the mechanics of a compound landslip are extremely complex. Nevertheless, certain general principles can be deduced and the more important factors affecting the slip can be determined with sufficient accuracy to predict the future behaviour of a slip.

What is not usually appreciated is the fact that the lateral extent of a slip is relatively small and that all large landslips are compound. The eastern face of the Trotternish ridge is formed by a series of intersecting arcs—as is the back of any large slip e.g. Blackgang in the south-west of the Isle of Wight, Herne Bay in Kent, the coast east of Redcliff Point in Dorset, and Walton Naze in Suffolk. But

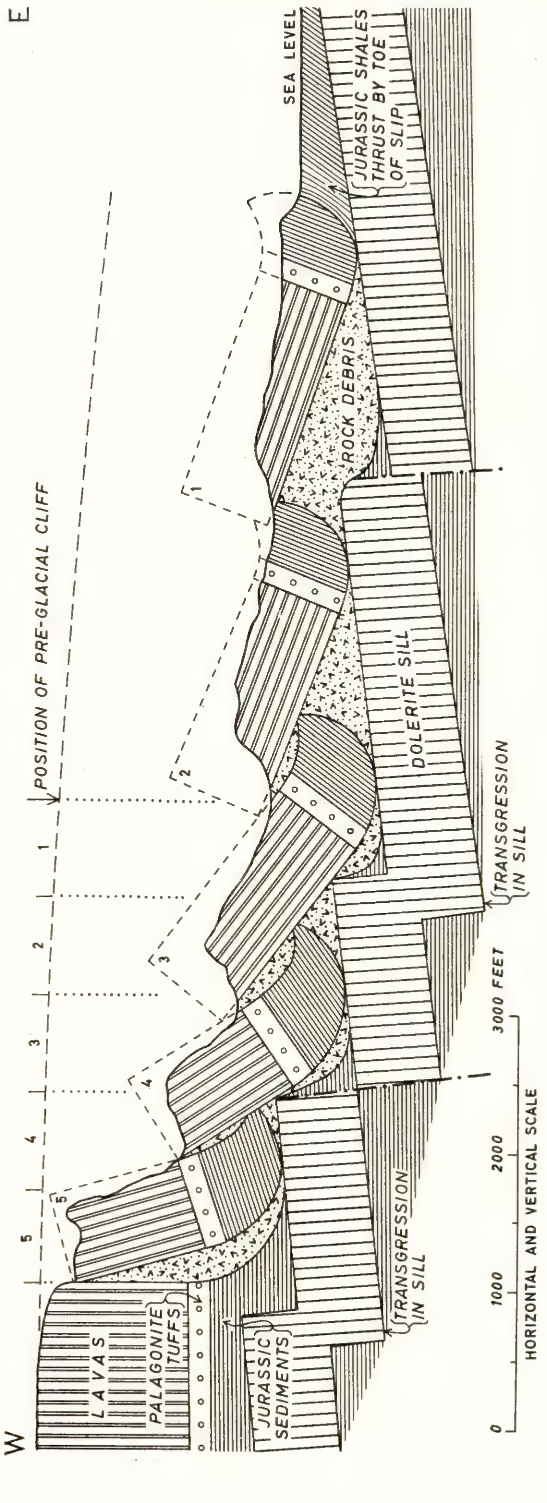


FIG. 22. *Section of the Quirang Landslip*

these are in reasonably homogeneous material. In Trotternish, however, the scarp is capped by basalt lavas and the arcuate back of the slip, which may be a segment of a circle at the top of the sediments, is modified by the non-plastic nature of the overburden and the proximity of joints. In addition there are several arcs of much larger radius which are the backs of corries and post-date the landslip. It is probable that the presence of a vertical joint plane in the lavas has determined the position of a glide-plane in the underlying sediments primarily because it would allow water to percolate and so help to reduce the coefficient of friction at this point. Apart from this the lavas are of little significance except that their weight supplies some of the motive force which activates the slip.

The glide-plane along which the slip moves is formed entirely in the sediments, in the beginning, at the base of the lavas, at the angle of shear, but immediately curving away to form by the integration of an infinite series of thrust-planes the characteristic curved back which is the trace of a logarithmic spiral.

All the factors involved are variables. The pressure (p) exerted by the overlying mass of rock is initially vertical and downwards but as the slipped material slips outwards the tilting of the moving block increases the horizontal component until at 45° this is at its maximum of $\rho/2$. As gliding continues the horizontal pressure falls to zero and the mass becomes stationary. Another variable is the angle of shear (θ). In dry clay this may be very small, i.e. the internal friction may be very high and the resultant fracture is then virtually parallel to the direction of maximum pressure. The addition of water, however, has the effect of reducing the internal friction. Theoretically, the angle of shear could vary between 0° and 45° which is the maximum possible in material such as paraffin wax where the internal friction is zero. E. M. Anderson (1951) has shown that for sedimentary rocks in general θ is about 20°. The fact that the sediments involved do not consist entirely of clay but may include beds of limestone, or even sheets of igneous rocks, does not seriously affect the issue provided they are strictly subordinate in thickness and are so placed that the glide-plane approaches them at a fairly obtuse angle.

Eventually the glide-plane approaches the horizontal and at about the same place the horizontal component of pressure is at its maximum. The slide from then on behaves as a thrust, the horizontal pressure usually at this stage being reinforced by pressure from the succeeding wedge. At the same time the forward elements are approaching the position of rest and there is an increasing resistance to forward movement which will in time entirely inhibit any further slip.

Most of the landslip in Skye appears to have reached a position of equilibrium, though examples of active landslip are to be found at Ben Tianavaig south of Portree and on the east side of Dun Caan in the neighbouring island of Raasay, outside the area of the present memoir.

The Quirang landslip (Plate IV; Fig. 22) is still a little unstable because the toe of the slip reaches the sea in Staffin Bay and is being constantly removed by marine erosion.

It remains to discover how many of the operative factors can be determined or calculated and how the principles of landslipping can be applied to individual examples in Skye.

The height of the operative free face (h^1) can in most cases be calculated with reasonable accuracy. In almost all the known landslips in Skye this is the thickness of sediment lying between the base of the lava-flows above and a major dolerite sill below. The total height of the free face (h^2) is the operative thickness of the sediments below, plus the thickness of the lava overburden. The distance from the free face to the margin of the slip (d) can be measured, as can the angle of rest (α) of the slip.

The angle of shear (θ) is theoretically variable from 0 to 45° and almost directly proportional to log μ (μ = shear strength). The relationship between θ and μ is expressed by the formula:

$$2\theta = \mathrm{I}\frac{1}{\mu} \text{ or}$$

$$\theta = \pm\, 450 \pm \frac{\omega}{2} \text{ where } \tan\omega = \mu \text{ (Anderson 1951).}$$

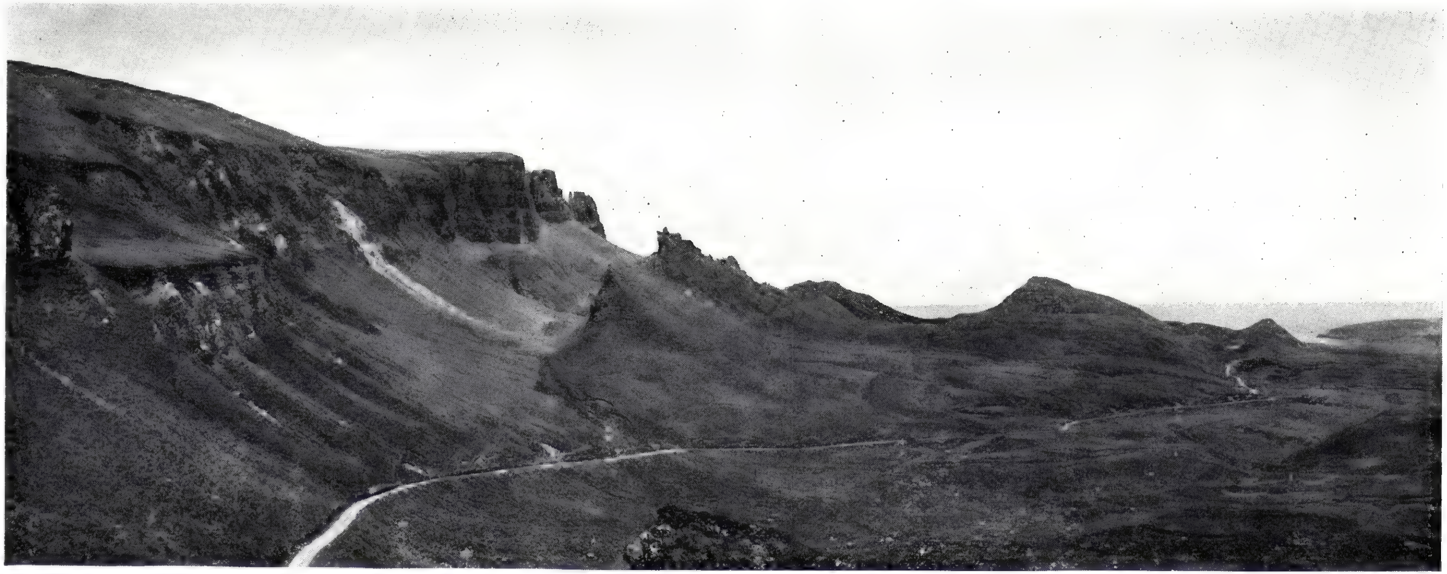
Thus when μ is very large, in practice ± 10, θ is virtually 0° and shear cannot take place. When there is no shear strength i.e. when $\mu = 0$, θ is 45°. Anderson (1951) has shown that the inclination of faults is on the average between 18° and 22·5°; i.e. μ for average sedimentary strata must range from 1·0 to 1·38. The value of μ for the Skye sediments is taken to be ± 1·2 (θ ± 20°). If this is so then the glide-plane is a logarithmic spiral of 20° and the relationship between the horizontal and vertical radii is $r^1/r^2 = 1{\cdot}3$ and it follows that the higher the free face, i.e. the greater the plane of minimum pressure, the greater the radii of curvature of the glide-plane.

The curvature of the back face is a segment of a circle of radius equal to that of the logarithmic spiral at the top of the free face, thus its radius of curvature (r^3) will be the same as r^1.

Examination of the landslip east of Trotternish lava scarp and south of the Quirang reveals that the generalized slope of the stabilized landslip is about 15° (β) which corresponds to a stable angle of 6° (α), i.e. the angle subtended by the plastic medium to the margin of the slip. The relations are d (distance of margin from scarp) = $h^1/\sin\alpha$ or $h^2/\sin\beta$. The latter is the more easily measured. When these angles reach these minimum values forward progress of the slip is halted. It follows that if the angles are greater the slip is unstable and further slipping may be expected.

Landslipping in Skye and Raasay. In late Tertiary times the lava plateau was tilted slightly to the west and considerably broken up by faulting. As a result of these dislocations the eastern sea-board from Portree to Kilmaluag must have been a cliff of remarkable dimensions probably reaching a height in places of at least 2000 ft. The lower half of this cliff would have been composed of Jurassic sediments and dolerite sills, whilst above stood a great thickness of lava-flows. Such an arrangement is obviously unstable and from the moment of its inception the sediments must have tended to slide under the weight of the super-incumbent lavas. Almost identical conditions to those in north Skye obtain in the Cascade Mountains in northern Washington, U.S.A., where the Columbia lavas in sheets 400 to 500 ft or more thick, rest on clays and sands, or on deposits of volcanic lapilli, and the series has been eroded so as to form steep escarpments. The type of landslip described from the Lookout Mountain in this area is very similar to that found in northern Skye (Sharpe 1938).

The Storr Landslip. The best known and most spectacular of the Skye landslip areas stretches from The Storr (2360 ft) across the glaciated trough partly occupied by Lochs Leathan and Fada and reaches out 5000 ft almost to the coast



(C3899-3900)

THE QUIRANG, LOOKING NORTH-EAST FROM UIG ROAD

Escarpment of Tertiary lavas with extensive area of landslipped masses of Tertiary volcanic material. Staffin is on the extreme right

[illegible] POLYTECHNIC LIBRARY

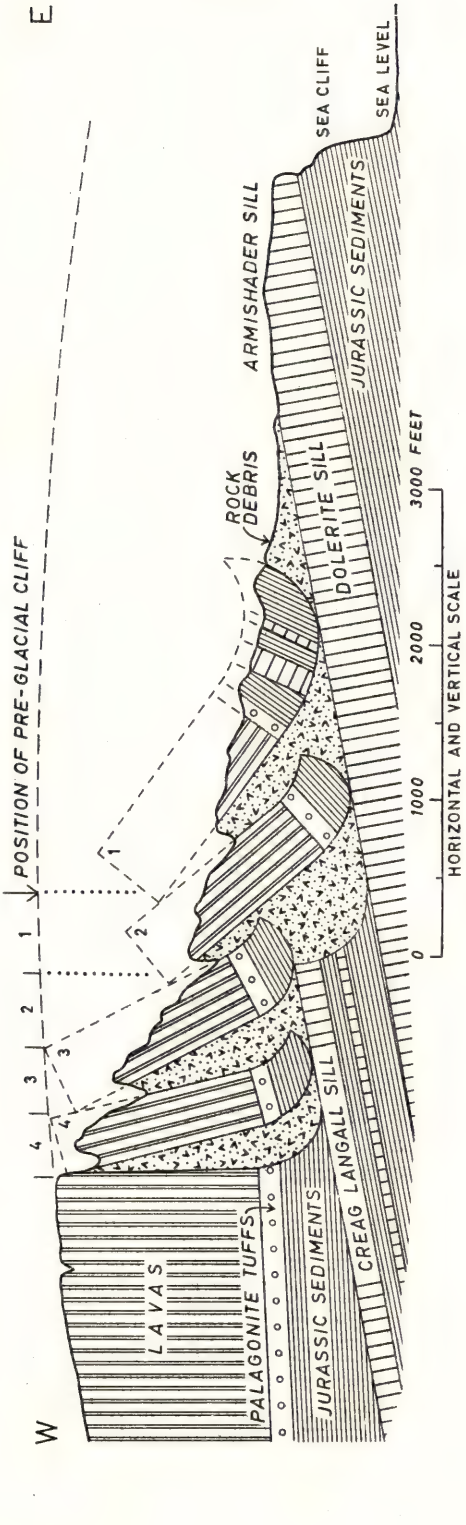


FIG. 23. *Section of The Storr Landslip*

(Plate I, Fig. 23). This is a mature stable slip with an angle of rest (β) of 15°. It is clear that the present slip is entirely post-glacial, its volume and extent being consistent with the existence of a pre-slip escarpment about 2000 ft east of its present position. The back face is in places over 2000 feet but is variable. The base of the lavas is, however, consistently at about 900 ft O.D. (The palagonite tuffs at the base of the lavas which may be of the order of 100 ft thick are included with the Jurassic sediments).

Thus 1000 ft of sediments lie between the thick Armishader sill and the lava-base, but included in them is the thinner Creag Langall sill, the top of which is 500 ft below the base of the lavas. Sills as thick as the Armishader intrusion appear to inhibit landslip. Thinner sills of which the Creag Langall sill is one, act as a base to the slip when approached obliquely by the glide-plane, but where this intersects the sill at a high angle it behaves as the base of a rigid block. These complications are well illustrated by The Storr Landslip (Fig. 23). The effective thickness (h^1) of incompetent strata in the present Storr slip has been always between 400 and 500 ft. Thus h^1 (500 ft), d (5000 ft) and α (6°) form a series of standard values which can be compared with those of other slips.

Though there is no evidence of present movement in The Storr landslip its stability can be only temporary since removal of the toe of the slip by erosion will probably lead to some compensatory forward movement. That such is the case is evidenced by the development of a fissure back from the escarpment edge marking the position of a future slip. The process will be, however, extremely slow.

In the upper part of the landslip the component segments are clearly visible and show the characteristic tilt of the vertical axis towards the back, but older blocks have been reduced by movement and weathering to chaotic heaps of rubble. The dimensions of the segments involved in any one slip appear to be partly controlled by the thickness of the plastic medium. In general the thicker the sediments the bulkier the moving block. Speed of movement is probably partly dependent on the mass of the lava-block above and the stage of maturity reached by the slip.

The Quirang Landslip. Situated west of Staffin Bay the Quirang Landslip (Fig. 22) is more extensive though less spectacular than that of The Storr. It is the greatest landslip in Skye and for that matter, in Britain, extending 7000 ft from the scarp of Meall nan Suireamach to the coast of Staffin Bay. This too is a mature slip, stable for the most part, though in the north near Flodigarry where the toe is being actively removed by the sea there is continuous though not extensive movement. The main road near Flodigarry is frequently dislocated. This same road provides a good section through the lower part of the slip showing tumbled masses of basalt lava in a gravelly rubble consisting largely of bole and decomposed lava.

The forward thrust of the toe has profoundly disturbed the underlying Jurassic sediments in Staffin Bay and beach sections of strata ranging from the upper beds of the Great Estuarine Series to the Kimmeridge Clay show beds dipping westwards at very high angles with the development of considerable overthrusts, the most evident being that which repeats the hard sandstone of the Belemnite Sands. The normal dip of these sediments is rarely more than 15°.

The basement of this slip is formed by the thick dolerite sill which composes Staffin and Flodigarry Islands. This is faulted and stepped so that although the dip is westwards the amount of sediment intervening between the sill and the base of the lavas remains fairly constant at about 700 ft. The stable angle (α) is 6°, the angle of slope (β) almost 15° so that the limit of slip (d) should be about 7000 ft as indeed in the stable portions it is. The height of the lava column is here much the same as at The Storr, being a little over 1000 ft. Since h^1 is greater here the slipped blocks are larger, some being almost 500 ft across, e.g. The Table.

Here the backward tilt of the constituent blocks towards the scarp is seen more clearly than to the south.

The pre-glacial slip which must have extended seawards from a scarp 3000 ft east of the present position and have had an altitude of at least 2500 ft was removed by the Highland ice which came ashore north of Rigg. The toe of this slip must have extended eastwards as far as Flodigarry and Staffin Islands.

Between The Storr and the Quirang the landslip fronting the lava-scarp is mature and stable. In places additional evidence as to the date of the slip is to be found. On the east side of Loch Cuithir are moraines belonging to a small glacier which flowed in a north-easterly direction from Creag a'Lain. Farther north a small local glacier in the Smearal River has almost removed the landslip. Patches of boulder clay are to be seen here and there on the landslip, particularly south of Beinn Edra, whilst erosion of the landslip margin by streams, in particular the tributaries of Abhainn Gremiscaig, shows that it is resting for the most part on boulder clay. The greater part of this section of landslip therefore was formed after the main glaciation and prior to the late-glacial readvance.

Mature landslips like those at Loch Losait in Vaternish are cut by the 100-ft Beach. On the other hand the toe of the Quirang landslip in places overrides the 25-ft Beach.

The Ben Tianavaig Landslip. The area on the east side of Ben Tianavaig on the south side of Portree Bay affords an example of an immature and unstable landslip.

At the close of the main glaciation the eastern face of this mountain must have presented a cliff face of about 500 ft largely determined by small faults.

The lower part consisted of Jurassic sediments (Lias, Inferior Oolite and the basal part of the Great Estuarine Series).

In the present slip 1000 ft of sediments separate a thick dolerite sill from the base of the lavas. Thus the margin of the slip should be almost 10 000 ft from the cliff face. It is in fact about 3500 ft to sea-level and the toe of the slip is being actively eroded. The slope (β) is about 21° and the slip unstable and landslipping may be expected to continue until the greater part of the mountain is removed. The radius of curvature of the slip plane (r^1) is about 1250 ft so that very large masses are involved in each sector of the slip; the most recent block to move is a rectangular mass exceeding 1000 × 1500 × 3000 ft, i.e. more than 16 million cubic yards.

The Dunn Caan (Raasay) Landslip. Although Raasay is outside the area of this Memoir the landslip east of Dunn Caan must be referred to since it is a unique example not only of a highly unstable slip but one which is known to have moved in recent times.

Compared with the Skye landslips this at Dunn Caan presents several unusual features. Firstly the cliff consists almost entirely of Jurassic sediments indicating that a lava overburden is not an essential feature of this phenomenon.

The back face comprises about 2000 ft of sediments in the middle of which is the competent Middle Lias sandstone. The history of this slip appears to have been firstly that of the beds overlying the Middle Lias ($h^1 = 1000$ ft), secondly slip of the L. Lias ($h^1 = 1200$ ft) with the Middle Lias acting as overburden, thirdly, of the Great Estuarine Series and overlying lavas ($h^1 = 500$ ft). The angle of slip is over 20°, and the sole extends only 3000 ft to sea-level where the toe is being actively eroded.

Thus the slip is highly unstable. On 7 August 1934 the local newspapers reported that twice within a period of six weeks a volcanic eruption had taken place in Raasay. Rising steam and smoke, showers of stones and loud rumbling noise were reported by local inhabitants. Professor A. D. Peacock, who visited Raasay shortly after the last reported occurrence, considered that the phenomena were due to stones falling down one of the very extensive fissures backing the latest slipped mass. But it seems more probable that such a spectacular disturbance was due to movement on a larger scale i.e. to renewed slipping of the unstable mass. The present author visited the locality almost 20 years later to find many new fissures and evidence of considerable and recent movement.

Other Landslips in Skye. There are several localities in northern Skye where the known presence of Jurassic rocks beneath the lavas has resulted in landslip and others where landslip suggests the existence of completely hidden sediments. For example on the north side of Loch Losait in Vaternish and on the west side of Dunvegan Head in Duirinish are typical slips but no sediments are exposed. On the other hand the landslip west of Waterstein Head in Moonen Bay contains fragments of Jurassic rocks though the outcrop is entirely covered by scree and slip.

The Conon inlier east of Uig is an amphitheatre of Corallian and Kimmeridge Clay shales surrounded by a wall of lava. Landslip has taken place all round the margin although the lava-base cannot anywhere be more than 20 ft or so above the floor of the inlier.

Rockfalls and Scree. Everywhere the lava-scarp and sill outcrops produce extensive scree. This is too commonplace to remark except that in two localities i.e. at The Storr and below Ben Essie, 1½ miles N.E. of Portree, the scree has become famous for its zeolites. In both places extensive suites of minerals have been obtained. Heddle (1901) records apophyllite, stilbite, natrolite, mesolite, thomsonite (variety fareolite), chabazite, levynite, laumontite and gyrolite.

Rockfalls are less common and are mainly formed by debris from the scarp of a columnar dolerite sill. Two outstanding examples are ½-mile S. of Rubha Garbhaig, Staffin, where the sea-cliff at the back of the 25-ft Raised Beach is a dolerite sill composed of large regular columns. These on breaking off have formed a rockfall composed of more or less cubical blocks many feet across which have accumulated as a loose aggregate and containing large cavities. This rockfall is later than the 25-ft Beach which it covers from cliff to coast.

The fall resembles landslip in that it is due to the presence of Jurassic sediments separating it from the underlying non-columnar dolerite sill which forms the present sea-cliff. But the blocks composing the fall lie entirely at random and there is no sign of the underlying pattern of a landslip.

A similar fall has developed under Cnoc Roll just south of Duntulm and is also formed by rocks from a columnar basalt sill resting on Great Estuarine sandstones and shales. This fall is much fresher in appearance than that of

Rubha Garbhaig and is in continual movement. The Uig-Kilmaluag road which crosses it is frequently shifted and broken.

Diatomite. Diatomite (Kieselguhr), a fresh-water lake deposit consisting largely of the remains of microscopic unicellular plants, is found in many places in Skye. Mixed with the siliceous skeletons of the diatoms is a varying amount of clay and peaty matter. The deposit is usually greenish in colour when wet but almost pure white and is very fine-grained and uniform in texture. All the occurrences seen suggest that this is not a deposit being formed at the present time for they are all covered with clayey or peaty soil.

At Loch Cuither, the most extensive deposit known in Skye, the diatomite, rests on moraine which is itself on landslip. The deposit is thus later than the latest glaciation and earlier than the peat.

The earliest post-glacial period (Pollen Zone I) was apparently wet and one of extensive solifluxion. In Skye this was probably the period of landslipping immediately following the retreat of the Highland ice. Pollen Zone II, with a dryer milder climate (Allerød) left no recognizable deposits in Skye, but Pollen Zone III, showing a return of a colder, wetter climate and a second period of solifluxion, is perhaps the period of the Scottish Re-advance and the development of valley glaciers.

Later came a climatic optimum during which it is suggested that diatomites were laid down. This may also be the period during which the *Chara* Marls which are found scattered all over Britain in a similar stratigraphical position to the diatomites but in a calcareous environment, were formed. Certainly a warmer climate than that at present obtaining is suggested.

Return to a less mild and wetter climate put an end to the diatomite-rich pools and instead peat formation began.

Diatomite is first recorded in Skye by Wilson and Macadam in 1886, but had been found earlier in Mull (Gregory 1853, 1854) and Lewis (Burgess 1882, Rattray 1887).

The diatom flora is rich in species; Wilson and Macadam (1888) recorded 78 species belonging to 23 genera from Loch Quire (Cuithir), Sartil (west of Stenscholl), Loch Snuisdale (Sneosdal) and Uig (Loch Chaluim Chille). Almost half the known Quaternary genera are represented. The Raphidae are represented by the genera *Amphora*, *Cymbella*, *Stauroneis*, *Pleurosigma*, *Navicula*, *Gomphonema*, *Rhoicosphenia*, *Achnanthes*, and *Cocconeis;* the Pseudo-Raphidae by *Epithema*, *Eunodia*, *Synedra*, *Fragularia*, *Diatoma*, *Denticula*, *Cymatopleura*, *Surirella*, *Campylodiscus* and *Nitzschia;* and the Crypto-Raphidae by *Cyclotella*, *Melosira* and *Euodia*. For a full list of species and their distribution Wilson and Macadams's account should be consulted.

Sartil is ¾-mile W. of Brogaig on the north side of Staffin-Uig road. Loch Cuithir is about 1 mile N.E. of Creag a'Lain, Loch Sneosdal is 1½ miles due E. and Loch Chaluim Chille ¾-mile W. of Balgown, all in Trotternish. Other localities where diatomite has been recorded are Loch Beannichte and a nearby dry pond on the Score Horan landslip, Loch Mealt, and Loch Cleat ¼-mile E. of Duntulm.

The composition of diatomite is discussed on p. 200.

Alluvium. Freshwater alluvium occurs chiefly as narrow strips along stream courses and the silted-up basins of lochans. The largest tract is that on the site of the old Loch Chaluim Chille, north of Uig in Trotternish. This Loch originally over one mile long and 90 ft above sea-level, occupied a glacially scoured hollow in dolerite sill which probably was once part of the 100-ft Beach, from which it is separated by a ridge of boulder clay now breached by the outlet stream and by artificial drainage channels. After unsuccessful attempts in 1715 and 1763 the loch was finally drained in 1824.

Additional channels were dug in 1947. The soil is peaty but nevertheless many acres of valuable pasture have been recovered.

Blown Sand. At An Corran, the promontory bounding Staffin Bay on the east, are large accumulations of sand both on the beach and heaped up against the cliff.

As a result of south-easterly gales the north-face on the eastern side of the promontory has been thoroughly sand-blasted. The dolerite of the cliff is highly polished and pebbles having a typical dreikanter shape are not uncommon on the beach.

Olivine Sand. The Tertiary basalt lavas and dolerite sills are frequently olivine-rich. In areas where these form part of the coast dark-green olivine and augite sands occur. Probably the best example in Skye is that described by Walker (1932) in Lub Score, Duntulm.

Musical Sands. The oil-shale which is found at the base of the Great Estuarine Series in the Portree area is replaced further north by a black sandstone composed of quartz grains unusually uniform in size and shape. This sandstone forms the north and north-eastern shore of Loch Leathan, the most northerly of the two lochs south-east of The Storr. The rock has been bleached by the overlying peat and weathers to a clean white sand which emits a musical note when struck. It is thought that the uniformity of grain-size causes sympathetic resonance to be set up so that the small vibrations caused by walking on the sand are amplified to audible volume.

Nullipore 'Sands'. In certain areas round the west coast of Skye the calcareous alga *Lithothamnion calcareum* Aresch flourishes in great abundance and broken fragments of the thallus form dazzling, creamy-white beaches which are composed almost exclusively of this material.

In Vaternish, Haldane (1937, p. 79; 1939, p. 442) has recorded beaches of *Lithothamnion* debris (commonly known as 'Coral Sands') from three bays, the largest known as Camas Ban, which lie north of Rubha na Gairbhe on the east side of Loch Dunvegan. At the most northerly of these is a small spit of sand and pebbles which connects the Lampey Islands with the mainland and which is uncovered at lowest tides. On it the unbroken algal colonies grow in clusters up to a few inches in diameter.

This kind of environment appears to favour the growth of *Lithothamnion* since another rich colony, that ½-mile N. of Ord in Sleat is found in a similar position—a spit of sand joining a small unnamed island to the mainland. Colonies of *L. calcareum* are not uncommon on the west coasts of England, Ireland and Scotland in the upper and lower sub-littoral zone. In places they have been dug for agricultural lime. Skye occurrences are known in Loch Bracadale at Camas Ban and Colbost Point.

REFERENCES

ANDERSON, E. M. 1951. *The Dynamics of Faulting and Dyke Formation with Application to Britain.* 2nd edit. Edinburgh.

BURGESS, E. W. 1882. Diatoms from the Island of Lewis. *J. Roy. Micr. Soc.* (2), **2**, 665-6.

CHARLESWORTH, J. K. 1956. The Late-Glacial History of the Highlands and Islands of Scotland. *Trans. Roy. Soc. Edin.*, **62**, 769-928.

GREGORY, W. 1853. Diatomaceous Deposit of Mull. *Quart. J. Micros. Sci.*, **1**, 242.

—— 1854. Additional observations on the Diatomaceous Deposit of Mull. *Quart. J. Micros. Sci.*, **2**, 24-8.

HALDANE, D. 1937. In *Sum. Prog. Geol. Surv.* for 1936.

—— 1939. Note on the Nullipore or Coralline Sand of Dunvegan, Skye. *Trans. Edin. Geol. Soc.*, **13**, 442-4.

HEDDLE, M. F. 1901. *The Mineralogy of Scotland.* 2 vols. Edinburgh.

PETTERSON, K. E. 1955. The early history of circular cylindrical sliding surfaces. *Geotechnique*, **5**, 275.

RATTRAY, J. 1887. A Diatomaceous Deposit from North Tolsta, Lewis. *Trans. Roy. Soc. Edin.*, **33**, 419-41.

SHARPE, C. F. S. 1938. *Landslides and related phenomena.* Columbia University Press.

SKEMPTON, A. W. 1953. Soil mechanics in relation to geology. *Proc. Yorks. Geol. Soc.* **29**, 33-62.

TERZAGHI, K. and PECK, R. B. 1948. *Soil Mechanics in Engineering Practice.* New York.

WALKER, F. 1932. An Olivine Sand from Duntulm, Skye. *Trans. Edin. Geol. Soc.*, **12**, 321-2.

WILSON, J. S. GRANT and MACADAM, W. I. 1886. Diatomaceous Deposits in Skye. *Mineral. Mag.*, **7**, 35.

—— 1888. Diatomaceous Deposits in Skye. *Trans. Edin. Geol. Soc.*, **5**, 318-26.

Chapter XIII

ECONOMIC GEOLOGY

IRONSTONE

CHAMOSITIC ironstone averaging 8 ft in thickness occurs in the Upper Lias of Raasay and was successfully worked for some years (Lee 1920, pp. 31-41; Macgregor 1920, pp. 196-202).

In bores put down at the mouth of the Bearreraig River in Skye the ironstone was found to be 5 ft 9 in thick and in the same stratigraphical position as in Raasay. Here, however, the rock is a greenish, ferruginous, oolitic limestone of much lower grade and different in composition. The iron in the Raasay workings is in the form of a silicate, here it is as a carbonate. The average iron-percentage in a sample analysed by Messrs. Baird was 11·96 per cent. A mile south of Bearreraig the ironstone was only 2 ft thick. Southwards, though Upper Lias strata occur at intervals as far as Tianavaig Bay, no ironstone has been observed. Were ironstone proved in the area north of or west of Bearreraig it would be under a great thickness of Inferior Oolite, Great Estuarine Series etc. and a variable thickness of Tertiary lavas. This together with its low grade makes the ironstone in Skye an uneconomic proposition.

JET

A thin band of jet was found by Tait in the *exaratum* Subzone of the Upper Lias, three-quarters of a mile south of Holm. The well-known Jet Rock horizon of Yorkshire is at this same stratigraphical level (Lee 1920, p. 39).

OIL-SHALE

The base of the Great Estuarine Series in Skye and Raasay is in some areas marked by oil-shale 8 to 10 ft thick which follows conformably on the clay of the *garantiana* Zone (Lee 1920, p. 47). In Raasay this is a true oil-shale similar to those worked in the Lower Carboniferous strata of the Lothians. Weathered samples analysed by Mr. D. R. Steuart of the Broxburn Oil Works gave 12 gallons of crude oil per ton of shale.

In Skye the oil-shale forms the base of the Great Estuarine Series from Ollach to Bearreraig. The seam is about 7 ft thick capped by some 3 ft of sandy bituminous shale. A compound sample from between Holm and Prince Charles's Cave yielded 12·8 gallons of crude oil per ton.

To the south the shale tends to pass laterally into an impure coal. Northwards it is replaced by a black sandstone.

LIGNITE

Lignite is found in small quantities at various horizons in the Jurassic rocks. As mentioned above, the oil-shale at the base of the Great Estuarine Series passes into a 'coal' south of Portree. Coal burnt by a dolerite sill occurs in thin streaks on the shore east of Achnahannait, south of Camastianavaig. Further south at Upper Olloch attempts have been made to extract coal from a lenticular seam between tide-marks. Impure coal is known from higher horizons in the Great Estuarine Series; for example, coal was at one time dug at Port na Cagain in baked shale (Ostracod Limestone), on the east side of Lovaig Bay and on the shore of Loch Bay, in Vaternish.

Tertiary lignite is more abundant but still not present in any economic amount. It occurs in the Palagonite tuffs at the base of the lavas; less frequently in the interbasaltic sediments which separate the main periods of eruption. A seam said to have been from 1 to 3 ft in thickness and to have yielded 500-600 tons was once wrought in Camas Ban on the south side of Portree Harbour (Macculloch 1819, p. 360). This and the occurrences at Loch Cuithir (MacCallum 1920) at Camastianavaig, Scoribreck and at Peinvraid in the Conon valley near Uig, were in the basal tuffs. Interbasaltic lignites are known near the head of Loch Greshornish, near Dunvegan, just south of An Ceannaich where a 1 ft 3 in-coal can be seen in shales and sandstones about 26 ft up the cliff; in shaly sandstone between two lava flows in the Hamra River; in tuffs just west of Airigh Neil; in bole half a mile south of Cnoc nan Braonar below a mugearite flow; and in dark shales in the Tungadal River, one mile north-east of Roineval. None of these are of any economic value, though that at An Ceannaich was reported by Geikie (1896, p. 342) to be glossy, hard, and of remarkable purity.

PEAT

Until recent years peat was the chief, indeed almost, the only fuel of the inhabitants but apart from this domestic use the economic possibilities of this material have not been exploited in Skye.

Much of the island is peat covered sometimes to considerable depth, but accurate figures for the thickness of peat are not available. When the road to the diatomite mine at Loch Cuither was made some 10 ft or so of peat had to be cut through before a firm foundation was reached and a similar thickness is known near Loch Mealt. In general peat-cutting has gone on to an average depth of 5-6 ft in most parts of the island.

The appearance of the old peat hags suggests that peat formation to-day is negligible and it is thought to have been at its maximum in the relatively cold, wet period immediately following the Atlantic climatic optimum.

DIATOMITE

Diatomite, used as an absorptive for nitro glycerine, as a polishing medium, filler, insulator, filter and in the manufacture of paint, is found in several places in Skye. For further details of the composition and uses of Diatomite the Geological Survey Wartime Pamphlet No. 5 should be consulted (Haldane, Eyles and Davidson 1940).

1. Sartil. Diatomite has been worked commercially at Sartil, 2 miles west of Stenscholl on the north side of the Stenscholl-Uig road, but the deposit is now exhausted. It was found in a small loch in the Quirang landslip which was drained and the diatomite taken by aerial ropeway to the village of Digg, a mile to the north-east, where a pier, now destroyed by the sea, had been built.

Analysis of the Sartil diatomite, air-dried, gave silica 88·09 per cent, lime etc. 0·75 per cent, ferric oxide 3·36 per cent, organic matter 7·79 per cent. After calcination the silica percentage rose to 95·54 per cent. Its absorptive value, calculated as increase in weight of the calcined diatomite after saturation was 2·84 (a good diatomite would have an absorptive value of 4·0).

The Sartil deposit was worked by the British Diatomite Company from 1908 until, in 1911, the workings were taken over by the Skye Mineral Syndicate Ltd. of Manchester. Work was finally abandoned in 1913.

2. Loch Vallerain. The old lake basin due east of Loch Vallerain and just north of Digg shows indications of diatomite. The extent of the deposit is unknown but is likely to be small.

3. Glashvin. A thin layer of diatomite was disclosed in a cutting at Glashvin during the reconstruction of the road from Staffin to Flodigarry, in 1937. The deposit occurs about 900 yd north of the road fork at Brogaig and quite close to the lowest point on the rim of a hollow lying just west of the road. The alluvium which occupies the floor of this depression might therefore, repay investigation.

4. Loch Cleat. Bordering this small loch just east of Duntulm, good quality diatomite has been found beneath the peat. But again the extent of the deposit is not likely to very great.

5. Loch Sneosdal. In the old loch basin west of Loch Sneosdal and about one and a half miles south-east of Heribusta, diatomite has been found below the peat. The extent of the deposit is unknown but the sample analysed from here was of good quality though the iron content was rather high. The air-dried material had the composition—silica 83·79 per cent, lime etc. 3·80 per cent, ferric oxide 7·75 per cent, organic matter 4·63 per cent. After calcination the silica percentage was 87·87 per cent and the absorption value 3·27.

6. Loch Chaluim Chille. This lake basin lying between Balgown and the east coast is almost one square mile in extent. It has now been drained but round the margin of the old loch diatomite has been found in several places. The deposit is very irregular. At the southern end it is mixed with sand and mud but to the north of the ruins of the old monastery which once stood on an island in the loch, the diatomite ranges from one to five feet in thickness with a like thickness of peat and mud above. In places the deposit is contaminated with mud and silt and in one instance there is a bed of sand in the middle of a three-foot thickness of diatomite. Two samples of the diatomite were analysed by Macadam. They gave I. silica 63·69 per cent, lime etc. 4·17 per cent, ferric oxide 9·13 per cent, organic matter 23·01 per cent. After calcination the silica rose to 82·72 per cent. The absorption value was 3·59. II. silica 82·91 per cent, lime etc. 0·93 per cent, ferric oxide 4·78 per cent, organic matter 11·38 per cent. Silica after calcination 93·55 per cent. Absorption value 2·66. The silica percentage is rather lower than the average but the absorption value remains high.

7. Loch Mealt. Diatomite is present in the marshy ground bordering the loch on the western side. The material is of good quality but lies below 10 ft of peat. The full extent of this deposit has not been explored.

8. Loch Beinnichte and a nearby dry lochan on the Score Horan landslip in Vaternish contain some diatomite deposits but their full extent, which cannot be great, has not been established.

9. Loch Cuithir. The loch named Cuithir is situated on landslip north-east of Creag a' Lain. The present loch is a much diminished remnant of a body of water which at one time must have covered about 24 acres. Within it the largest diatomite deposit so far known in Skye was formed. The diatomite ranges from 8 ft to 18 ft in thickness (40 ft in Strahan and others 1917, p. 38) and is covered by an average thickness of 3 ft 8 in of peat. The material is very pure with no included bands of mud or silt.

Macadam's analyses show that the calcined diatomite contains over 96 per cent of silica (98·78 per cent *in* Strahan and others 1917, p. 38), and has an absorptive value of over 3·56.

The Loch Cuithir diatomite was originally worked by the British Diatomite Company, later by the Skye Mineral Syndicate Company. A three-mile tramway connected the diggings with the shore at Inver Tote.

Road Metal

Most of the Skye roads are constructed of local material usually dolerite taken from small conveniently adjacent quarries in the Tertiary sills. This provided hard core and the top dressing, before the relatively recent introduction of macadam, was the fine brown chloritic material found where the sill has been deeply weathered or rotted by a transcurrent dyke.

Inverness County Council have extensive diggings in the 25-ft Raised Beach at Sconser just south of the Portree (80) Sheet from which sands and gravels composed of granite, quartzite, sandstone, grit, basalt, porphyrite and hornfels fragments are obtained for use as road aggregate.

Limestone

Some of the limestones in the Great Estuarine Series are of fair quality but in general are not sufficiently good or accessible to be worth exploitation for anything but local use (Phemister *in* Muir and others 1956, p. 132).

Shell Sand

The distribution of the shell and nullipore 'sands' of N. Skye has been described on p. 196. The latter is often of good quality. The analysis of a sample from Camas Ban, 4½ miles N.N.W. of Dunvegan and ¾-mile W.N.W. of Claigan, by Muir and Hardie (*in* Muir and others 1956, p. 64) showed 84·32 per cent $CaCO_3$ and 10·35 per cent Mg CO_3. The 'sand' has at times been dug locally for agricultural lime. It is estimated that a minimum of 2500 tons is available in Camas Ban (Claigan) at low tide, and rather less than half this at high tide. The total amount available is of the order of 5000 tons (Haldane 1939, p. 442; Robertson and others 1949, p. 125).

Honestone

Indurated Jurassic shale is a common feature in North Skye where the Tertiary dolerite sills have caused extensive alteration. In places, such as on the north side of Cairidh Ghlumaig, Duntulm, the shale has been converted into buchite, a rock in which abundant minute prisms of the mineral mullite have developed. Mullite is a compound chemically and physically identical with artificial sillimanite ($3Al_2O_3.2SiO_2$) and with a lower refractive index than true sillimanite ($Al_2O_3.SiO_2$). The rock therefore would serve as a honestone, but has never been exploited for this purpose (see Bailey and Anderson 1925, pp. 76-7; Bowen, Greig and Zies 1924, p. 183).

WATER

Much of the domestic water in Skye is obtained from springs and wells supplemented in the larger communities by concrete cisterns and collecting tanks. Portree has a reservoir just north of the town fed by the R. Chracaig and Staffin is supplied from Loch Cleap. The water is acid and after periods of heavy rain is usually a rich brown due to included organic material from the peat.

In the landslip areas water-supply is difficult since most of it drains through the slip and emerges at its margins in the form of springs. Hydro-electric power has now been developed in the Portree area. The Bearreraig River, the outlet for Lochs Leathan and Fada, was dammed about 10 years ago and the level of the two lochs raised. The power house, situated on the 25-ft Beach at the mouth of the Bearreraig River, now supplies electric power to Portree and its woollen mill. In the south of Skye electricity is supplied from the mainland grid.

REFERENCES

BAILEY, E. B. and ANDERSON, E. M. 1925. The Geology of Staffa, Iona and Western Mull. *Mem. Geol Surv.*

BOWEN, N. L., GREIG, J. W. and ZIES, E. G. 1924. Mullite, a silicate of alumina. *J. Washington Acad. Sci.*, **14**, 183-91.

GEIKIE, A. 1896. The Tertiary Basalt-plateaux of North-western Europe. *Quart. J. Geol. Soc.*, **52**, 331-406.

HALDANE, D. 1939. Note on the Nullipore or Coralline Sand of Dunvegan, Skye. *Trans. Edin. Geol. Soc.*, **13**, 442-4.

HALDANE, D., EYLES, V. A. and DAVIDSON, C. F. 1940. Diatomite. *Geol. Surv. Wartime Pamphlet No.* 5, 1-13.

LEE, G. W. 1920. The Mesozoic Rocks of Applecross, Raasay and North-East Skye. *Mem. Geol. Surv.*

MACCALLUM, D. A. 1920. *In* Discussion on H. H. Eiriksson. Coal Mining in Iceland. *Trans. Inst. Mining Eng.*, **59**, 269-70.

MACCULLOCH, J. 1819. *A Description of the Western Islands of Scotland including the Isle of Man.* 3 vols. London.

MACGREGOR, M., LEE, G. W. and WILSON, G. V. 1920. The Iron Ores of Scotland. *Mem. Geol. Surv. Min. Resources*, **11**.

MUIR, A., HARDIE, H. G. M., MITCHELL, R. L. and PHEMISTER, J. 1956. The Limestones of Scotland, Chemical Analyses and Petrography. *Mem. Geol. Surv., Min. Resources*, **37**.

ROBERTSON, T., SIMPSON, J. B. and ANDERSON, J. G. C. 1949. The Limestones of Scotland. *Mem. Geol. Surv., Min. Resources*, **35**.

STRAHAN, A., FLETT, J. S. and DINHAM, C. H. 1917. Potash-Felspar, Phosphate of Lime, Alum Shales, Plumbago or Graphite, Molybdenite, Chromite, Talc and Steatite (Soapstone, Soap-Rock and Potstone), Diatomite. *Mem. Geol. Surv., Min. Resources*, **5**, 2nd edit.

Appendix I

List of Geological Survey Photographs

Taken by Messrs. R. Lunn and W. D. Fisher

Copies of these photographs are deposited for public reference in the library of the Geological Survey, South Kensington, London, S.W.7 and in the library of the Geological Survey Office, 19 Grange Terrace, Edinburgh, 9. Prints and lantern slides are supplied at a fixed tariff on application to the Director. All numbers belong to Series C (Half plate).

Tertiary

2251	Basic dykes cutting plateau—basalts (lavas) of Tertiary age. Rubha Buidhe.
2252	Step-like features ("trappen") characteristic of the plateau-basalts with intrusive basalt sill. South of Portree.
3899-3900	Escarpment of Tertiary lavas with area of landslipped Tertiary volcanic material. The Quirang from U-bend, Uig Road. (Plate IV.)
3901	Escarpment of Tertiary lavas and landslips. The Quirang, from Kilmaruy Burial Ground.
3902	Escarpment of Tertiary lavas and landslip. The Quirang and Prison Rock.
3903	Escarpment of Tertiary lavas showing shattering due to landslipping. The Quirang, The Needle etc.
3904	Shattering of Tertiary lava escarpment due to landslipping within The Quirang.
3905	Isolated stack of Tertiary lava. The Needle, The Quirang.
3906	Escarpment of Tertiary lavas with landslip in foreground. Sron Vourlinn, from Kilmaluig Road.
3907	Tertiary lava escarpments with extensive landslip areas. Beinn Edra and The Storr from the Quirang.
3908-9	Escarpments of Tertiary lavas with landslips. Biod Buidhe and Beinn Edra from the Quirang.
3913-4	Northern escarpment of Tertiary lavas. North end of Trotternish Basalt Plateau.

Jurassic

2236-8	Exposure of Oil-Shale overlying the Inferior Oolite and forming base of the Great Estuarine Series. South of Holm.
2239	Middle Lias Sandstone with calcareous nodules (doggers). South of Holm.
2241	Exposure of Lower Oolite Sandstone giving rise to waterfall. Bearreraig. (Plate IIA).
2242-6	Exposure of Lower Oolite overlain by sill of dolerite. Berreraig Bay (C 2244 is reproduced here as Plate IIIA).
2247	Lower Jurassic rocks capped by Tertiary plateau-basalts. Ben Tianavaig.
3917	Jurassic sediments overlain by an intrusive dolerite sill. Leallt Gorge.

INTRUSIONS

2240	Features given by Jurassic rocks with intrusive sills of dolerite. Holm.
2248-50	Columnar sill of intrusive dolerite. Rubha Buidhe.
3896	Columnar dolerite sills of Tertiary age, intruded into horizontally bedded sediments of Great Estuarine Series. The Kilt Rock, North Trotternish.
3897	Columnar dolerite sills of Tertiary age intruded into horizontally bedded sediments of Great Estuarine Series. Mealt waterfall and Kilt Rock, North Trotternish.
3898	Jurassic sedimentary rocks with intruded sills of dolerite. Coast south of Mealt waterfall looking north from Valtos (Plate IIIB).
3910	Escarpments of Tertiary lavas with Jurassic sediments intruded by sills of dolerite. Creag a'Lain, and The Storr from Elishader.
3911-2	Escarpment of Tertiary lavas with Jurassic sediments intruded by dolerite sills. North end of Trotternish Plateau from near Duntulm Post Office.
3915-6	Large intrusive sill of columnar dolerite. Meall Tuath.
3918	Irregular dyke cutting lavas. Lyndale Point.
3919	Dyke showing columnar jointing. Lyndale Point (Plate IIB).

The photographs MN20704-6 forming the Frontispiece are from colour transparencies taken by Dr. F. W. Anderson.

INDEX

Four-figure National Grid references to localities in Northern Skye are given in italics; all relate to National Grid square NG.

Aa-aa lava, 102
Aalenian, 12
Abhainn Bhaile Mheadhonnaich *3243*, 90
—— Gremiscaig *4762*, 76, 193
—— nan Cnoc *4860*, 185
Abhuinn nan Leac, 175
Achacork *4746*, 185
Achnacross, 163
Achnaha (Ardnamurchan), 155
Achnahannait *5037*, 199
A'Chorra-bheinn *4748*, 86
Achtalean *4646*, 111, 163, 169
Acklington type of dykes, 157–8
Age-determinations, 80
Agglomerate, 4, 139
Aird Point *4053*, 138
Airigh Neil *3649*, 82, 199
Algal Beds, 8, 21, 23, 37–41, 43, 48, 50–1, 174
Allan, J. K., iii, viii
Allerød, 195
Allivalite, 81, 136–7, 154–7, 170
Allt an Lon Ghuirm *3549*, 152
Allt an t'Sluic Mhoir *2753*, 43
—— Dearg *3848*, 151, 157
—— Fionnfhiachd, 111, 163
—— Garbh *3947*, 135
—— Mor *3740*, 82, 90, 183
—— na Ba Grasion, Loch Sligachan, 76
—— na Glas Bhuaile *2544*, 135
—— Ruairidh *3444*, 82, 90, 136
—— Yelkie *3860*, 134, 151
Alluvium, 4, 195–6
Almond, D. A., 150, 158, 163, 171
Am Bidean *3441*, 136, 155–6
—— Bile *5044*, 133–4, 152
Ami Boué, see Boué
Amoeboceras Beds, 56–7
Ampthill Clay, 65
Amygdaloidal lavas, 83, 93–4; layer of lava, 101–2; structure (tuff), 75
Amygdaloids, defined, 104
An Bord, 140
—— Carnach, 163
—— Ceannaich *1350*, 174, 199
—— Cleireach *3344*, 81, 136
—— Corran *4968*, 39, 45, 126, 129, 196
—— Da Bheinn, 175
—— Leitir *4536*, 138
—— Lethpheighinn *1946*, 135
—— Stac *1446*, 26
Anderson, E. M., 189–90, 197, 202
——, F. W., iii, viii, 8, 17–9, 21, 23, 37, 43, 48, 54–5, 73, 78
——, J. G. C., 202
——, T., 128
Antrim lavas, 79–80, 94, 98, 162
Applecross, 1, 132
Ard Beag *2161*, 36, 95, 134, 157
Ardassie Point, 11
Ardmore Bay *2260*, 36, 42, 186
—— Point *2159*, 125
Ardnamurchan, 80, 94, 155
Ardnish, 173
Ardroag *2743*, 135, 156
Ardtun, 74, 77
Arid climate, 48
Arkell, W. J., 8–9, 17, 59, 71
Armishader *5050*, 25, 128, 192
Aros Bay *2760*, 133
Arran, crinanite sills, 146
Aschenstructur, 73
Ascrib Islands *3064*, 2, 127, 137, 147

Baca Ruadh *4757*, 76
Bailey, E. B., 94, 100, 116, 121, 123, 137, 139, 150, 152–3, 157–8, 160, 163, 171–172, 176, 202
Baird, Messrs., 12, 198
Bajocian, 12, 54
Balgown *3868*, 47, 185, 195, 200
Ballykeel Townland, 163
Balmacquien *4374*, 45
Balmeanach *5234*, 138, 184, 186
Balnaknock *4162*, 70–1
Basalt, 4–5, 81–92, 98–116, 120–1, 150, 153–155, 160–9
Basic sills, of Skye, nature of group, 80, 94
Bay River *2753*, 43
Beal Chapel *4944*, 75
—— Point *5145*, 10, 95, 98, 103, 110
Bealach a'Chairn *4853*, 3
—— a'Chaol-reidh *4649*, 180–1
—— Chaiplin *4560*, 3
—— Hartaval *4755*, 3, 108, 117, 119
—— Iochdarach *4173*, 41
—— na Leachaich *4659*, 3
—— Uige *4464*, 179, 182
Bearreraig Bay *5153*, 15–7, 128, 134, 174, 182, 184, 198, 203
—— Grit, 5, 12–6, 21–2, 24

Bearreraig River *5152*, 3, 12, 16, 198, 202
'Beef', 23, 25, 36, 43, 47–8
Beinn a'Chapuill *4353*, 181
—— a'Chearcaill *3547*, 179, 182
—— a'Chleirich *3345*, 136, 156
—— a'Sga *4269*, 135, 180–1, 183
—— an Dubhaich Granite, 175
—— an Laoigh *4360*, 180–1
—— an Righ *4456*, 180–1
—— Bheag *3959*, 181
—— Bhreac *2553*, 3, 87, 89, 120, 127, 177
—— Dearg, 182
—— Edra *4562*, 3, 83–4, 86, 117, 179–80, 193, 203
—— —— Anticline, 174
—— —— group of lavas, 81–2, 86, 89, 91, 116
—— Eirisalain *3252*, 90
—— Fhuar *4260*, 181
—— Mheadhonach *4749*, 183
—— na Boineide *2952*, 89–90
—— na Caillich (Sleat), 175, 177–8, 182
—— na Cloiche *3641*, 157, 183
—— na Greine *4541*, 88, 152, 182
—— na Seamraig, 177
—— nan Braclaich *3440*, 136
—— nan Lochan *3837*, 90
—— Totaig *4036*, 88
—— —— group of lavas, 81–2, 88–91, 116
—— Tuath *4352*, 81, 135
Belemnite Beds, 16
—— Sands, 5, 8, 18–20, 50, 52–4, 56, 58, 60–61, 68, 192
Ben Aketil *3246*, 90, 183
—— Aslak, 177
—— Chracaig *4943*, 13
—— Connan *1940*, 87
—— Corkeval *1844*, 87
—— Duagrich *3938*, 88, 139
—— Essie, see Rubha na h-Airde Glaise
—— Geary *2561*, 87–8, 151
—— Grasco *4344*, 88
—— Lee *5033*, 81, 163, 179
—— Meabost (S. Skye), 163
—— Sca, see Beinn a'Sga
—— Scudaig *3540*, 90, 176
—— Tianavaig *5140*, 11, 75, 81, 86, 112, 138, 179, 189, 203
—— —— Landslip, 193
—— Tote *4150*, 184
—— Uigshader *3749*, 88, 138, 153, 179, 183
—— Vokie Fault, 175
—— Volovaig *4376*, 127, 146–8
Benmoreite, 119
Big-feldspar mugearite lava type, 101
Biod a' Ghoill *2859*, 35, 111–2
—— an Athair *1655*, 1
—— Ban *1349*, 1, 139
—— Buidhe, 203
Bituminous shale, 56
Black Cuillins gabbro, 132
—— Sandstone, 18
Blackgang, 187
Blackhill, 97
Blath Bheinn, 175
Blaven, 182
Blown Sand, 196
Bogen, 73
Bogha Ruadh *4475*, 45
Bole, 76–7, 81, 83–5, 89–90, 94, 101–2
Bolfa, J., 108, 123
Bombs, 73
Bornaskitaig *3771*, 126–7
Borve *4448*, 185
Boué, A., 7, 17
Boulder Clay, 4, 25
Boust Hill *3537*, 90
Bowen, N. L., 164, 171, 202
Bracadale *3538*, 2, 81–2, 115, 117, 119, 122, 127, 133, 135–7, 153, 156, 179, 182–3
—— group of lavas, 81–2, 90–1, 116, 135
Braes of Skye, 175, 179
Braigh a'Choir' Mhoir (Mull), 163
Braon a'Mheallain *3840*, 89
Breabost Burn *3652*, 151
Breccia, igneous, 4
Breun Phort *4968*, 129
Bridport, 15
British Diatomite Company, 200–1
Brito-Arctic region, 170
Broadford, 1, 133, 178
—— Beds, 173
Broc-bheinn (Sligachan), 113, 163
Brogaig *4768*, 63, 195, 200
——, River *4667*, 48, 63, 69, 182, 185
Broisgillmore Burn *3441*, 136, 155–6
Brora Roof Bed, 54
Brown, G. M., 155–6, 158, 164–5, 170–1
——, P.E., 80, 92
Broxburn Oil Works, 198
Bruach na Firthe (Cuillins), 163
Brunton type of lava, 150
Bryce, J., 8–10, 17, 36–7, 43, 52, 54, 63, 71
Buckman, S. S., 10, 59, 71
Bun-idein *4276*, 45
Burgess, E. W., 195, 197

Cadha an Tuill *5066*, 34, 39
Cairidh Ghlumaig *4073*, 40–1, 186, 202
—— nan Ob *3670*, 126, 186
Caisteal Disdein *3858*, 153
Calcareous Sandstones, 18, 174
Caledonian earth-movements, 173
Callomon, J. C., 54
Callovian, 174
Camas Ban *4942*, 75, 95–8, 129, 196, 199, 201
—— Beag *3761*, 82, 135
—— Fhion-nairidh, 175

Camas Mor *3770*, 47, 126, 147, 163, 186
—— nan Sithean *1347*, 26, 131
—— Sgiotaig (Eigg), 34
Camastianavaig *5039*, 4, 9, 11–3, 21, 95, 128, 199
Camasunary Fault, 174–5
Cambrian rocks, 1, 172–3
Carboniferous rocks, 173
Cardioceras Beds, 56–7
Carn Liath *4956*, 76, 182, 185
—— More (Strathaird), 54
Caroy River *3044*, 3
Cascade Mountains, 190
—— Volcanic rocks, 168–9
Casey, R., 43, 54
Causeway type basalt, 100
Cementstones, 19, 25, 39, 42–5, 47–9, 52, 56–8, 60–4, 66–71
Central massive layer of lava, 101
—— type Mull basalt, 100
—— volcano of Cuillin Hills, 90–1, 132
'Challenger' expedition, 98
Chara Marls, 195
Charlesworth, J. K., 179, 197
Chayes, F., 109, 123
Chevalier, R., 108, 123
Chracaig, River *4844*, 75, 104, 127, 182, 202
Clach Bhuidh *2654*, 76
—— Chraigisgean *3769*, 185
Clachan *4866*, 47
Claigan, see Camas Ban
Clett *2258*, 36
Clough, C. T., 6, 55, 123, 132–4, 139, 158, 171–2, 176
Cnoc a'Chrochaire *3144*, 135
—— na Cairidh *2654*, 36
—— nan Braonar *3339*, 199
—— Roll *4173*, 46, 194
—— Steud *3860*, 134–5
Coal and coaly films, 75–6
Coir a'Mhadaidh (Cuillins), 155
—— an t' Seasgaich *4758*, 185
Coire Amadal *4461*, 181–2
—— Chaiplin *4459*, 181–2
—— Cuithir *4658*, 182, 185
—— Faoin *4953*, 83, 107
—— Fuar *4557*, 181–2
—— Iomhair *4458*, 135, 181–2
—— na Banachdich (Cuillins), 177
—— Scamadal *4954*, 182
Colbost *2149*, 135
—— *3140*, 90
—— Point *3039*, 135, 196
Cole, G. A. J., 93, 152, 158
Columbia lavas, 190
Columnar structure, 3, 14, 75, 81, 83, 94, 102, 126, 129, 204
Concretionary Sandstones, 5, 8, 18–20, 23, 25–37, 39, 42–3, 46–7, 129, 131
Cone-in-cone structure, 50, 53
Connista *4373*, 40
Conon, River *4063*, 3, 70–1, 76, 81, 194, 199
Coombs, P., 99
Copnahow Head, see Gob na Hoe
Coprolites, 32
'Coral Sands', 196
Corallian, 4–5, 7–9, 19–20, 49–50, 52–3, 56–8, 60, 62, 64–70, 76, 127, 129, 131, 174, 194
Cornbrash, 18–9, 48
Corran *4152*, 138
Coulomb's equation, 187
Cox, L. R., 8, 17, 19, 21, 23, 37, 43, 54
Craig, R. M., 172, 176
Craig Skulamus Fault, 175
—— Ulatota *5047*, 12, 27, 74, 95, 128
Creag a'Chait *4838*, 88
—— a' Lain *4658*, 3, 193, 195, 201, 204
—— an Airgid (Ardnamurchan), 155
—— an Locha *4155*, 180–1
—— Bhreac *3741*, 157
—— Chragach *4161*, 180–1
—— Langall *4958*, 129, 134, 153, 192
—— Madragil *4255*, 133, 181
—— Moine *4253*, 182
—— Mor *5145*, 95–9, 102–3, 109–10, 150, 163
—— na Cuthaige *4157*, 182
—— na h-Eiginn *4672*, 126, 140
—— nam Bodach *2051*, 76–7
—— nam Meann *4055*, 184
Creagan Iar *4073*, 127
—— Mora *3743*, 183
—— na Sgalain *5139*, 9, 11, 13, 75
Cretaceous, 51, 174
Crinanite, 134, 146
Cruachan Beinn a'Chearcaill *3546*, 90, 179
—— Glen Vic Askill *3646*, 136, 183
Crystal-vitric tuff, 75, 95, 160
Cuillin granite, 175
—— Hills, 1, 90, 93, 132, 136–7, 155, 160, 174, 177–9, 182, 184–5
Cuithir *4658*, 185
Culnaknock *5162*, 29, 48
Cunningham Craig, E. H., 134, 139, 146, 158
Curidh nan Ob, see Cairaidh nan Ob
Current bedding, 33, 172–3
Cyclic sedimentation, 19–20, 26–29, 31–2, 36–7
'*Cyrena*' Limestones, 18, 23, 34
—— Shales, 18, 23

Davidson, C. F., 199, 202
Davies, A. Morley, 59, 71
Deer, W. A., 106, 123, 169
Desert pavements, 73
Dessication cracks, 73
Devonian rocks, 173
Diatomite, 4, 195, 199–201
Digg *4669*, 63, 200

Dinham, C. H., 202
Doggers, 9, 13, 19, 25–9, 31–2, 35, 203
—— date of formation, 34
Dolerite, including picritic, crinanitic and teschenitic varieties, 134–5, 137, 141–151, 153, 155
Domerian, 9
Dorset, 15, 57, 59, 65, 187
Dreikanter, 196
Drever, H. I., 141, 145, 158
Druim Fada *4373*, 185
—— na Coille *4364*, 182
—— na Criche *4337*, 88–90, 94, 116–7, 119–121, 152, 161, 163
—— na Slochd *4672*, 45, 126–7, 129, 140, 142
Drum Dearg *5164*, 30
Drumuie *4546*, 81
Drynoch, 111, 134, 163
—— group of dykes, 133, 153
Dubh Allt *4741*, 152
Duirinish, 1–3, 26, 35, 36–7, 77, 81, 86, 135, 177–8, 185, 194
Dun *4866*, 47
—— Arkaig *3542*, 136
—— Borrafiach *2363*, 127, 157
—— Caan, 179
—— —— Landslip, 189, 193–4
—— —— Shales, 10
—— Connavern *5062*, 38, 48
—— Dearg *5164*, 30–1, 39, 129
—— Flashader *3553*, 151, 157
—— Grianan *5259*, 24, 129
—— Raisaburgh *5064*, 142
—— Sgalair *4148*, 184
—— Torbaig, 22
Dunham, K. C., iii, 104, 123
Dunmull Toberdornan, 163
Duntulm *4174*, 7–8, 35, 37, 40, 63, 126–7, 129, 135, 146, 179, 181, 184, 194, 196, 200, 202, 204
—— Castle *4174*, 40, 46, 146
Dunvegan *2547*, 1, 89, 156, 186, 199, 201
—— Head *1756*, 1–2, 36, 87, 135, 194
Dykes, 4, 6–7, 14, 22, 24, 30, 43, 45–6, 48–9, 58, 60, 64, 67, 75, 77, 130, 132–9
——, age relations, 138–9
—— of N. Skye, types, 149

Eaglais Bhreagach *5259*, 24, 129
Earth movements, 174
Eas na Coille *4637*, 134
Edinbain *3451*, 90, 97–8, 117, 120, 135, 152, 156, 182–3
Edwards, W. N., iii, 74, 77
Eigg, 7, 23, 34, 37
Eilean a'Bhaird (Canna), 163
—— Altavaig, see Eilean Flodigarry
—— Chaluim Chille *3769*, 53–4, 63, 186, 195, 200
Eilean Creagach *2965*, 137
—— Flodigarry *4871*, 45, 184
—— Mhuire (Shiant), 147, 167
—— Trodday *4478*, 126–7, 140, 147–8
Eist *1246*, 26, 36, 125, 130–1
—— Fhiadhaich, see Oisgill Bay
Elishader *5065*, 39, 47, 129, 204
Ennos, F. R., 99
Eocene, 4, 175
Erosion, late-Tertiary, 79
——, Pleistocene, 79
Erratic boulders, 185
'*Estheria*' Shales, 5, 14–5, 18–21, 23–7, 29, 129–31, 143, 174
Eucrite, 155
Eyles, V. A., 98, 123, 199, 202

Fairfield Cottage *2746*, 153, 156
Fasach *1848*, 185
Faulting, Block, 6
Feldspar-phyric olivine-basalt type, 101
Fionn Choire (Cuillins), 163
—— Chro (Rhum), 163
Fisher, W. D., 203
Fissure eruptions, 79
Fiurnean *5149*, 13–4, 27, 74, 126, 128–9, 131
—— Shales, 5, 10, 12, 14, 15
Fladda-chuain *3681*, 126, 140, 147
Flett, J. S., 134, 146, 151, 158, 202
Flinty crush, 172
Flodigarry *4671*, 4, 45, 65, 70, 76, 81, 95, 126, 129, 142, 184, 192–3, 200
—— Hotel *4671*, 45, 69
Flora Macdonald's Grave *4071*, 148
—— —— Monument *4071*, 42, 46
Folding, 4, 172–5
Forbes, E., 7–8, 17, 51–2, 54, 57, 72
Forse Burn *2440*, 77, 82
Forsyth, I. H., 12, 17, 19, 54
Fossil wood, 95
Francis, E. H., 100, 153
Fuller, R. E., 73, 78, 124

Gabbro, 136–7, 154–7, 170
Gaeilavore *3679*, 140
Gairbh-sgeir *3871*, 42, 47, 138
Gamlingay, 65
Garadubh *4736*, 152
Garantiana Clay and Sandstone, 5, 12, 14–7, 19, 21–2, 24
Garbh Eilean, 140–2, 145, 147, 163
Gardner, J. S., 78, 80, 92
Gearran Island *3679*, 140, 174
Geary *2661*, 137
Geikie, A., 93–4, 123, 140, 158, 199, 202
Geo Mor *2039*, 151
Geodh' an Tairbh *1655*, 36
Geodha Dubh *3765*, 50–1
Gesto House *3536*, 90, 96, 139

Glaciated valleys, 185
Glaciation, 6, 177; early local, 177; Scottish Re-advance, 195
Glamaig, 175, 182
Glas Bheinn *3736*, 136
—— —— Mhor, 175
Glashvin *4668*, 63, 200
Glen Bracadale *3739*, 139
—— Brittle, 182
—— Colbost *3442*, 90
—— Drynoch *4330*, 182, 185
—— Hinnisdal *4057*, 138, 180, 182
—— Osdale *2343*, 77, 82, 89
—— Ose *3241*, 136, 139, 183
—— Sligachan, 182
—— Uig *4163*, 3, 76, 134, 179, 180–2, 185
—— Varragill *4737*, 137–8, 179, 182, 184–5
—— Vidigill *3936*, 153
Glendale *4818*, 77, 157
Glenelg, 177
—— glacier, 179
Glengrasco *4444*, 138
Glenmore River *4339*, 116, 182, 184–5
Glenuachdarach *4358*, 81, 135
Globe-breccia, 73–4
Gob na Hoe *1542*, 36, 135, 151, 157
Goodchild, J. G., 94, 113
Graded bedding, 172
Gravitational differentiation of sills, 140
Grealin *5061*, 29
Great Oolite, 19
—— Estuarine Series, 4–5, 7–9, 12–5, 17–21, 36–7, 49, 51, 54, 56, 58, 60, 68, 71, 74, 127–9, 174, 192–4, 196, 198–9, 201, 203–4
Greenland, 170
Gregory, W., 195, 197
Greig, J. W., 202
Greshornish House *3454*, 135, 138, 160
Grosebay, 1
Guppy, Eileen M., 97, 103, 110, 123, 155

Haldane, D., iii, viii, 98, 196–7, 199, 201–2
Halistra *2459*, 95, 160
Hallival (Rhum), 155
Hamada formation, 73
Hamra, River *1848*, 77, 82, 135, 157, 185, 199
Hardie, H. G. M., 201–2
Harker, A., iii, 1, 6, 55, 80, 89, 92–5, 111, 113, 116, 119–21, 123, 125, 127, 132–4, 139, 141, 152–3, 155, 158, 163, 165, 171, 176
Harlosh *2739*, 90
Harris, 1
Harta Corrie *4723*, 132
Hartaval *4755*, 104, 117, 119, 152, 163, 182
Hatch, F. H., 93
Haultin River *4451*, 179–82
Hawaii lavas, 115, 169
Headington Shell Bed, 65
Healaval Bheag *2242*, 3, 86–7, 115, 177, 179, 182, 185
—— Mhor *2144*, 3, 77, 177, 179, 182, 185
Hebridean lava type, 100–1, 103, 162
—— type basalt, 86–8, 91
Hebrides, 19, 80
Heddle, M. F., 94, 104, 113–4, 123, 194, 197
Herdsman, W. H. and F., 103, 111
Heribusta *4070*, 42, 46, 129, 200
Herne Bay, 187
Hess, H. H., 105, 108, 123
Highland Ice, 178–9, 181, 184–5, 193, 195
Hinnisdal *4158*, 135, 179, 181, 185
—— Bridge *3957*, 86
Hodgkinson, Dr., 152
Hoe Point *1640*, 36
Holm *5151*, 9, 16, 21, 128, 198, 203–4
—— Island *5251*, 4, 10–2, 15, 134, 184
—— Sandstone, 5, 12–6, 22
Holmes, A., 157–8
Holocene, 4
Honestone, 201–2
Horne, J., 6, 55, 176
Howarth, M. K., 10, 17
Hudson, J. D., 8, 17–9, 23, 37, 43, 54
'Hummocky drift', 185
Hunglader *3871*, 42, 129
Hunish *4076*, 35
Hydro-electric power, 3, 202

Iceland, 80, 92, 98, 115
Ice-flow, Highland, 6
Ice-polished surfaces, 177
Idrigil *3863*, 2, 70, 87
Inferior Oolite, 4–5, 7–9, 12–5, 19, 21, 24, 75–6, 128, 173–4, 193, 198, 203
Inner Hebrides, 8, 12
—— Sound, 179
Interbasaltic sediments, 77, 79–80, 82, 89
Intrusions, 2, 4
Inver Tote *5260*, 4, 21, 23–5, 131, 201
Inverness County Council, 201
Ireland, 80
Ironstone, 198
Isay *2156*, 125, 186
Island Magee, Antrim, 103, 109
Isle of Purbeck, 7
—— —— Wight, 7, 187

Jameson, R., 7, 17
Jehu, T. J., 17, 176
Jet, 198
—— Band, 11–2
—— Rock, 11, 198
Johnson, T., 74
Johnston, R., 105, 123, 141–2, 158
Judd, J. W., 8–9, 17, 19, 36, 54, 93–4, 123, 140, 152, 158, 174

Jurassic rocks, 1–5, 7
—— —— effect of glacial erosion, 184

Kellaways Beds, 8, 18, 54
'Kelt Rock', 8
Kendrom *4373*, 71
Kennedy, W. Q., 89, 92, 94, 116, 120–4
Kent, 187
Kettle-moraine, 185
Khan, M. A., 80, 85–6, 92, 94, 123
Kieselguhr, 195
Kilbride Point *3766*, 50, 126, 135
Kildonan *3553*, 135, 137
Kildorais *4671*, 45, 67, 70
—— Fault, 61
Kilmaluag *4273*, 45, 50, 126, 129, 135, 142, 179, 186, 190, 195, 203
—— Bay *4475*, 39–40, 45, 140–1, 174, 179, 184, 186
—— River *4372*, 40, 45–6, 71, 185
Kilmartin River *4965*, 39, 44–5, 182, 184
Kilmaruy Burial Ground *4667*, 69, 203
Kilmuir *3870*, 146
Kilt Rock *5066*, 3, 31, 34–5, 126, 129, 142, 148, 204
Kilvaxter *3869*, 47
—— Burn *3869*, 47
Kimmeridge Clay, 4–5, 7–9, 19–20, 49, 56–8, 60, 64–71, 76, 129, 131, 141, 174, 192, 194
King, B. C., 111, 123, 163, 171
Kingsburgh *3955*, 174
Kinloch (Loch Dunvegan), 135
—— Hotel (Mull), 163
Kishorn Thrust, 175
Kosmoceras Beds, 56–7
Knock Vatten *2642*, 153
Knockbreck *2660*, 137
Knockhoe *3770*, 63
Knox, J., iii, viii, 76, 134, 138–9
Kuno, H., 170–1

Lacroix, A., 104, 123
Lambert, R., 144
Lampay Islands *2255*, 185, 196
Landslips, 3–4, 6, 11, 28, 35–6, 51, 64, 70–1, 76, 81, 87, 95, 129, 177, 182, 184–95, 201–2
Lapilli, 73
Laterite-like soil, 102
Lateritic clay, 77
Lava, 4, 5; brecciated, 81; vesicular, 81
—— flows, composite, 89, 94
—— suites, 79; magmatic sources, 90–2
Lawrie, T. R. M., iii, viii, 134, 138
Lealt, River *4959*, 3, 23–5, 28–9, 48, 76, 129, 131, 134, 182, 184–5, 203
Lee, G. W., iii, 1, 6, 8–10, 17, 19, 21, 48, 54, 76, 78, 198, 202
Leidlite, 134, 153
Lewis, diatomite in, 195
Lewisian rocks, 1, 172–3
Lias, 4, 7, 9–12, 173, 193
Lignite, 21, 76, 199
Limestone, worked for lime, 43, 201
Lincro *3966*, 63
Loch Ainort, 182
—— Alsh, 177–9
—— an Rathaid, 174
—— Bay *2655*, 4, 36–7, 43, 48, 76, 95, 178–179, 186, 199
—— —— Faults, 76
—— Beag *3538*, 90, 135–6
—— Beannichte *2859*, 195, 201
—— Bracadale *2838*, 3, 87, 135, 137, 139, 183, 186, 196
—— Caroy *3042*, 152, 186
—— Carron, 178–9
—— Chalium Chille, see Eilean Chalium Chille
—— Cleap *4666*, 202
—— Cleat *4174*, 195, 200
—— Cuil na Breig, 111
—— —— —— Creig, 163
—— Cuithir *4759*, 184–5, 193, 195, 199, 201
—— Dearg *4535*, 89
—— Dunvegan, 2, 76–7, 135, 178–9, 185–6, 196
—— Eilean (Morven), 163
—— Eisort, 178
—— Eyre *4152*, 138, 182
—— Fada *4949*, 3, 27, 37–8, 76, 126–7, 147, 179, 190, 202
—— Gairloch, 178
—— Greshornish *3454*, 3, 88, 134, 137–8, 199
—— —— Faults, 176
—— Harport *3635*, 88, 90, 133, 138, 182
—— Hourn, 177–8
—— Langaig *4670*, 60
—— Leathan *5051*, 3, 16–7, 25, 27–8, 34, 38, 47, 179, 190, 196, 202
—— Leum nam Bradh *4770*, 58
—— Losait *2759*, 35, 193–4
—— Mealt *5064*, 29–30, 39, 47, 127, 129, 132, 195, 199
—— Mor *1448*, 26, 36
—— Pooltiel *1550*, 135
—— Scavaig, 178, 182
—— Slapin, 178, 182
—— Sligachan, 125, 128, 140, 163
—— Sneosdal *4169*, 195, 200
—— Snizort Beag *3954*, 2–3, 35, 77, 137–8, 174, 178–81, 183–5
—— Staffin Beds, 7–8, 19, 57
—— Torridon, 178–9
—— Vallerain *4669*, 200
—— Vatten *2843*, 135, 185
Lon a'Ghlinne *4946*, 27
—— a'Mhuilinn *4665*, 44, 63

Lon Airigh-uige *4263*, 134
—— an t-Sithein *4946*, 27
—— an t' Sratha *4261*, 70–1
—— Breac *4156*, 135
—— Buideil *5064*, 47
—— Chaorach *4836*, 137
—— Coire na h'Airidh *4949*, 27, 38, 95
—— Druiseach *4947*, 26–7, 74–5, 131, 147, 182, 185
—— Glas *4766*, 63
—— Loch Mhair *4059*, 138
—— Mor *4452*, 179, 181, 185
—— nan Achadhanan *4443*, 138
—— Onstatoin *4072*, 41–2, 46, 142
—— Ruadh *4056*, 135
—— Salach, 138
—— Sgapail *3871*, 42, 46
Lonfearn *5161*, 25
—— Burn *5161*, 25
Lookout Mountain, 190
Lothians oil-shale, 198
Lovaig Bay *2355*, 43, 199
Lower Calcareous Grit, 59, 61
—— Callovian, 54
—— Halista *2459*, 76
—— Lias, 8, 194
—— Ollach *5137*, 13
—— Oolite, 203
—— '*Ostrea*' Beds, 5, 8, 18, 20–1, 26–8, 30–32, 34–43, 45, 47–8, 51, 129
—— Oxford Clay, 53, 57
Lub a'Sgiathain *4176*, 35, 45, 126
—— Score *3973*, 35, 138, 174, 186, 196
—— Stac nam Meann *4376*, 179
Lunn, R., 203
Lyndale Point *3657*, 77, 139, 204
—— Tuffs, 82

MacAdam, W. I., 195, 197, 200–1
MacCallum, D. A., 199, 202
Macculloch, J., 7, 17, 80, 92–3, 123, 125, 139–40, 158, 199, 202
Macdonald, Helen A. H., 96
MacGregor, A. G., 55, 116, 123
Macgregor, M., 202
MacGregor, Malcolm, 8, 17, 19, 45, 48, 51, 54
Macleod's Tables, see Healaval Mhor and Bheag
McQueen's Loch *5241*, 138
Maligar *4864*, 129
Manum, S., 80, 92
Maoladh Mor *4368*, 84, 111
Marishader *4963*, 39, 48
Marsco, 175, 182
Mathieu, S., 108, 123
Meall an Fhuarain *4635*, 77, 135
—— Brataig *4474*, 142
—— Greepa *2643*, 137
—— nan Suireamach *4469*, 3, 126, 179, 192
Meall Tuath *4176*, 35, 46, 126–7, 134, 140, 144–5, 149, 204
Meallan Gainmhich *4435*, 135, 138
Mealt Loch *5065*, 3, 47, 127, 132
—— waterfall *5065*, 35, 39, 47, 127, 129, 142–3, 147, 163, 204
Meanish *1550*, 135
Mesozoic rocks, 1
Middle Ampthill Clay, 65
—— Lias, 4–5, 8–11, 14–5, 128, 141, 173, 194, 203
—— Oxford Clay, 57
Miller, Hugh, 34, 54
Miller, J. A., 80, 92
Mills, A., 7, 17
Mingay *2257*, 36, 42, 125, 127, 146
Minginish, 90
Mitchell, G. H., iii
Mitchell, R. L., 202
Moine rocks, 173
—— Thrust, 173, 175
Mointeach nan Tarbh *1348*, 26, 130–1
Monkstadt *3767*, 186
Moonen Bay *1446*, 3–4, 26, 87, 194
Moraine, 4, 185
Mottled Clays, 5, 18–21, 40, 45, 47–53, 60, 65, 68
Muck, 37
Mugearite, 81, 83, 87, 89–91, 101, 116–22, 133, 152
Mugeary *4439*, 88, 115–7, 119–20, 160, 163, 178, 182
Muir, A., 201–2
Muir, I. D., 94, 109, 111, 116–7, 119, 124, 161, 163–4, 169, 171
Mull, 7, 74, 79, 80, 94, 116, 121, 137, 150, 158, 163, 195
Multiple dykes, 137–8
Murchison, R. I., 7, 9, 17, 19, 51, 53–4. 63
Murchison, Lady, 15
Murray, K. L. H., 103, 110, 119, 142, 155
Murray, R. J., 141, 158
Musical sands, 34, 196
Mylonite, 172

Narrows of Raasay, 175
Neaverson, E., 59, 72
Necker-de-Saussure, L. A., 7, 17
Nielson, N., 73, 78
Nockolds, S. R., 168–9, 171
Nodules, calcareous, 11, 50, 56–7, 69; concretionary, 61, 66, 70; phosphatic, 13; septarian, 25, 50–1
Noe-Nygaard, A., 73, 78
Non-sequence, 10, 12
North Atlantic Plateau, 79
—— Minch, 147
—— Scapadal, 174
Nullipore 'Sands', 196, 201
Nunatak, 179

Oans *2859*, 35, 87
Ob nan Ron *4968*, 39
Oil-Shale, 5, 12–4, 17–9, 21, 24, 76, 203
Oil-shale, 5, 19, 56, 198–9
Oisgill Bay *1349*, 1, 3–4, 26, 81, 131, 139, 141–3, 174
—— Burn *1349*, 26
Old Man of Storr *5054*, 28, 38, 51
Oligocene, 80
Olivine Sand, 196
Ollach *5136*, 86, 179, 198
—— Sandstone, 5, 12–5
Ollisdal *2138*, 135
Oolite, 11–2
Orbigny, A. D'., 59, 72
Ord (Sleat), 196
Oronsay *3136*, 90
Orval (Rhum), 163
Osborn, F. F., 168–9, 171
Osdale *2445*, 90
—— *3241*, 136, 139
—— group of lavas, 77, 81–2, 87, 90–1, 116, 135
Ose Point *3041*, 186
——, River *3442*, 136, 186
Osmigarry *3971*, 35, 42
Ostracod Limestones, 5, 18–20, 32, 35–7, 39, 41–8, 50, 129, 199
'*Ostrea*' *hebridica* Beds, 18
—— Limestone, 25
Outer Hebrides, 1, 172–3, 179
Overlap of Tertiary, 21
Oxford Clay, 4–5, 7–9, 19–20, 52–4, 56–8, 60–3, 65, 67–8, 129, 131, 174
—— ——, Zones used by Arkell, Buckman, d'Orbigny, Morley Davies, Neaverson, Pringle and Spath, 59, 61

Pabba Shales, 173
Pacific Ocean, palagonite from, 97–8
Pahoehoe lava, 102
Palagonite, definition, 98
—— Tuffs, 4–5, 13–4, 21–2, 36, 71, 73–6, 79, 91, 95, 99, 128–9, 132, 139, 160, 199
—— ——, effect of glacial erosion on, 184
'*Paludina*' *scotica* Limestones, 18, 43
Paper shales, 23, 25, 42
Patterson, E. M., 94, 124, 163, 171
Peach, B. N., 1, 6, 18–9, 34, 43, 48, 54–5, 172, 176
Peacock, A. D., 194
Peacock, M. A., 73–4, 78, 97–8, 104, 124
Peat, 4, 25, 27, 38, 199, 202
Peck, R. B., 187, 197
Pegmatitoid segregations, 85, 89, 102, 109
Pein a'Chleibh *4847*, 128
Peinchonnich *4063*, 76
Peinchorran, 76
Peingown *4071*, 42, 46, 129
Peinvraid *4163*, 76, 199
Peneplane, 4, 175
Pennant, T., 7, 17
Pennycross House (Mull), 163
Permian rocks, 173
Petterson, K. E., 187, 197
Pflug, H. D., 80, 92
Phillips, J., 8
Phemister, J., 100, 201–2
Physical features, 1
Pictonia Beds, 56
Pillow structure, 73–4, 98, 150, 152, 160
Pipe amygdales, 73–4, 98
Plant remains, 4, 22, 82
Plastic clay, 16
Plateau type of lava, 100
Platy structure, 133
Pleistocene, 4
'Pods', igneous, 135–6, 155
Poldorais *4771*, 64
Poll a' Bhaine *3454*, 138
—— an Staimh *3764*, 48, 51
Pollard, W., 111, 119, 121, 155
Pollen zones, 195
Port a'Bhata *5044*, 13, 21–2, 128
—— Beag *3237*, 138
—— Duntulm *4074*, 46
—— Earlish *5262*, 25, 29, 129
—— Gobhaig *4375*, 39–40, 45
—— Kilbride *3766*, 50
—— Lag a'Bhloedhainn *4176*, 46
—— na Cagain *2459*, 48, 127, 199
Portree *4843*, 1–3, 9–11, 13, 16, 21–2, 26–7, 73–7, 81–2, 88, 91, 93, 95, 98, 111–2, 114–5, 121, 127, 129, 132–4, 152, 160, 175, 178–9, 181–2, 184–6, 189–90, 194, 196, 199, 202–3
—— Anticline, 174
—— Bay, 184, 193
—— Fault, 175–6
—— Lodge *4843*, 75
—— Shales, 5, 10, 12, 14–5
Portrush, 163
Prince Charles's Cave *5148*, 9–10, 95, 198
—— —— Point *3766*, 47, 50
Pringle, J., 8–9, 59, 72
Prison Rock *4568*, 203
Purbeck, 19

Quaternary, 4, 177–96
Quenstedtoceras Beds, 56–7
Quirang *4569*, 3, 70, 84–6, 104, 108, 111–4, 177, 188–90, 192–3, 203
—— Landslip, 192–3, 200
—— Syncline, 174

Raasay, 1, 8, 10, 12–3, 15–9, 23, 36–7, 48, 174, 177–9, 184, 189, 198
—— Ironstone, 5, 10–2
Radley, E. G., 99, 147, 155

Rain pitting, 172
Raisaburgh *5064*, 39, 47
Raised Beaches, 186
Ramaskaig *1644*, 87
—— group of lavas, 77, 81–2, 86–7, 89, 91, 116
Rattray, J., 195, 197
Recumbent fold, 172
Red Burn *3150*, 3, 82
—— Cliff *4843*, 95
—— Hills, 1
Redcliff Point, 187
Remnant magnetism, 80; correlation of lavas by, 85–6
Remanié deposits, 12
Rha, River *4065*, 117, 119, 163, 179, 185
Rhaetic rocks, 173
Rhum, 80, 156, 164, 170
Richey, J. E., 9, 17, 19, 55, 94, 105, 123–4, 139, 155, 158–9, 171
Rigg *5156*, 25, 28, 128, 131, 193
—— Burn *5055*, 21, 25, 128–9, 182, 184
—— Sandstone, 5, 12–6, 22, 24
Ripple markings, 32, 45
River Chracaig *4844*, see under Chracaig
Road metal, 201
Robertson, T., iii, viii, 201–2
Rock falls, 4, 186, 194
Rodding on dykes, 132–3
Rodmor Peninsula, 151
Roineval *4135*, 77, 88–90, 94, 120, 152, 199
Romesdal River *4354*, 179–82, 185
Rona, 174
Ros a'Mheallain *3740*, 90, 119–20, 122, 163
Rosenbusch, H., 157, 159
Ru Bornaskitaig *3771*, 126
—— Chorachan *3761*, 135
—— Idrigal *3763*, 70
—— Vannarain *4475*, 40
Rubh' a Chairn Leith *3670*, 126
—— Bheanachain *4475*, 40
Rubha an t-Sean-Chaisteil (Mull), 163
—— Ban *4968*, 39
—— Bhreidein *3656*, 138
—— Buidhe *5136*, 203–4
—— Dearg (Loch Aline), 163
—— Dubh *2262*, 138
—— Garbhaig *4968*, 8, 19, 32, 34, 37, 41–2, 45, 126, 129, 184, 194–5
—— Glas *2661*, 137
—— Hunish *4077*, 2–3, 35, 126, 132, 140, 143, 144–6, 178
—— na Gairbhe *2253*, 196
—— na h-Airde Glaise *5145*, 10, 22, 74, 95, 103, 107, 110, 179, 194
—— nan Brathairean *5262*, 131, 184
—— nan Cudaigean *3854*, 137
—— Sughar *5153*, 16, 128

Sabine, P. A., 96–7, 103, 110, 123, 155
Sahlbom, N., 147
Saint-Fond, B. F., 7, 17
Salen (Mull), 163
—— type dykes, 99, 157–8
Sand and Gravel, 4, 185
Sartil *4568*, 195, 200
Scalpa, 9
—— Sandstone, 5, 9–12, 14–5
—— Series, 9–10
Scarborough Limestone, 16
Scarf Caves *5142*, 9–10
Schairer, J. F., 164, 171
Sconser, 201
Scoon, J. H., 111, 119
Score Horan *2859*, 3, 35, 42, 105, 111–2, 195, 201
Scoribreck *4843*, 199
Scorr Skerry *5042*, 10
Scree, 4, 76, 81, 130, 186, 194
Sedgwick, A., 51
Septarian nodules, 25, 48, 67, 70
Sequanian, 8
Sergeant, G. A., 97
Seward, A., 77
Sgeir Bhan *4967*, 129
—— Eirin *4872*, 184
—— Gharbh *5262*, 26
—— Lang *3670*, 42
—— nam Faoileann *4968*, 34, 39, 129
—— nan Eathar Bana *4474*, 45
—— —— Maol *3981*, 127
Sgurr a'Bhagh *2555*, 95
—— a Mhalaidh *4656*, 134
—— Ruaidh *4758*, 182
Sharpe, C. F. S., 190, 197
Sheets, inclined, 139
Shell sand, 201
Shiant Islands, 105, 127, 140–2, 147, 149, 162–3, 165, 167
Shulista *4274*, 45
Sideromelane, 73, 95–6
Sills, 4, 6–7, 14, 22–5, 27–32, 34–6, 38, 42, 44–5, 49, 53, 58, 60, 64, 66, 69, 75, 125–31, 141
——, coal burnt by, 199
——, effect of glacial erosion, 184
——, shales indurated by, 25–6, 32–5, 39–41, 43–8, 50–1, 61, 69–70, 201, 204
Silurian rocks, 173
Simpson, J. B., 80, 92, 202
Sipöcz, A., 97
Sithean Bhealaich Chumhaing *5046*, 11, 13, 23, 27, 74, 86, 153, 179, 182
Skaergaard Intrusion, 168–70
Skeabost *4148*, 186
Skempton, A. W., 187, 197
Skeirinish Duns *4151*, 184
Skerries, 140
Skriaig *4440*, 88
Skye, 7, 15, 17–9, 21, 23, 26, 34, 36–7, 43, 48, 56–7, 65, 69, 73–4, 79–80, 89–91,

Skye—*continued*
    93–4, 98, 100, 102, 109, 128, 131–2, 140, 146, 155, 162, 164, 170, 172–5, 177, 179, 181, 184–7, 189–90, 193, 195–6, 198, 201–2
—— Mineral Syndicate Ltd., 200–1
Sleat, 1, 133, 173, 175, 177–8, 182, 184
Sligachan, 132, 134, 178, 182, 184–5
Slochd Mor *2753*, 43, 48
Slump bedding, 16, 172–3
Smearal River *4465*, 193
Snake River Plateau, 73
Snizort, River *4246*, 153
Soay, 178
—— Sound, 178
Solifluxion, 73
Solitote *4274*, 186
Sound of Raasay, 134, 178–80, 182
SPATH, L. F., iii, 9, 56, 59, 67, 72
Spitzbergen, 80
Sron Vourlinn *4571*, 184, 203
Stac Buidhe *4474*, 45
Stack of Scudiburgh *3764*, 51
Staffa type basalt, analysis, 99
Staffin *4868*, 3–4, 27, 47, 76, 84, 95, 114, 129, 179, 184–6, 194, 200, 202
—— Bay *4869*, 7–8, 19, 48, 50–2, 57–9, 61–63, 65–8, 70, 125, 129, 182, 184, 189, 192, 196
—— Island *4969*, 2, 4, 39, 129, 184, 192–3
—— Lodge *4868*, 45
STARKIE GARDNER, J., 74
Steall a' Ghreip *4673*, 126
Stein *2656*, 43, 48, 95
STEINER, A., 113, 124
STEUART, D. R., 198
STEVENS, A., 173, 176
STEWART, F. H., 124
Stone polygons, 73
Storav's Grave, 12, 19
Stornoway, conglomerates near, 172–3
—— Thurst, 173
STRAHAN, A., 201–2
Strathaird, 1, 19, 23, 34, 37, 43, 48, 54, 150, 163, 174–5, 178
Strenscholl *4767*, 44, 186, 195, 200
Strollamus, 37, 111, 163
Strone Geers *2949*, 90
Struan *3538*, 90, 136
Struanmore *3437*, 90
STUBBLEFIELD, C. J., iii
Studley Brickyard, 59
Subzone, *Cardioceras cardia*, 57, 59, 62, 68
—— —— *excavatum*, 57, 61–3, 68, 70
—— —— *praecordatum*, 57, 59, 63
—— *Harpoceras excavatum*, 11–2, 198
—— *Quenstedtoceras vertumnus*, 57, 59, 62–3
Suffolk, 187
Suidh 'Fhuin *4642*, 77
Sulishadermore *4743*, 77
Sumardale River *3736*, 90, 138
Summary of Geology, 4
Sun-cracks, 32, 172
SWEET, JESSIE M., 94, 104, 114, 124

Talaidh type of lava, 150
TAIT, D., 11, 198
Talisker *3732*, 89, 120
Tanna Point, see Udairn
Tarscavaig Thrust, 173
Tarner Island *2938*, 134
TATE, R., 8–9, 37, 43, 51–2
Tertiary igneous rocks, 1–5, 7, 22–3, 70, 198, 201, 203
—— plutonic rocks, 1
—— sediments, 4, 13, 21–2, 27, 95–6, 160
—— volcanic activity, age of, 80; explosive phase, 79; fissure phase, 79; sources, 90
TERZAGHI, K., 187, 197
The Aird *4375*, 184
—— Braes *5234*, 179
—— Needle *4569*, 203
—— Storr *4954*, 3, 28, 81, 83–6, 94, 104, 106–8, 111, 113–7, 177, 179, 182, 184, 190–4, 196, 203–4
—— —— Landslip, 190–2
—— Table *4569*, 84, 193
Tholeiite, 157–8
THOMAS, H. H., 94, 105, 124, 155, 159
THOMSON, T., 104, 124
THORNTON, C. P., 164, 171
Thrust faults, 172
Thulean province, 79
Tianavaig Bay *5138*, 75–6, 86, 102, 184, 198
Tidmoor Point, Weymouth, 62
TILLEY, C. E., 94–5, 109, 111, 116–7, 119, 124, 142, 157, 159, 161, 163–4. 169, 171
Toarcian Stage, 10
TOMKEIEFF, S. I., 94, 100, 103–5, 109, 124
Tom na h' Uraich *4474*, 45
Tora River *4047*, 135
Torr Beag *5333*, 76
—— Mor *5333*, 76
Torran, 1
Torridonian, 172–5, 177, 184
——, earth-movements before, 172
Torvaig *4944*, 22, 75, 95
Totardor *3639*, 117, 119, 163
Totscore *3866*, 65, 129, 186
Tottrome *5154*, 38, 47, 179
Trachyte, 90–1, 101, 122, 133, 153
Transgression of sills, 128
Trappides, defined, 104
Treaslane River *3950*, 138
Tree trunk, fossiliferous, 48
Triassic, conglomerates, 172–3
Trigonia Beds, 65

Trotternish, 1–4, 6, 8, 23, 26, 34–5, 37, 42–3, 47, 51, 70, 81, 85, 125–7, 133–5, 140, 143, 145–7, 151, 160, 164–5, 174, 176, 178–82, 184–5, 187, 189–90, 195, 203–4
Trumpan *2261*, 36
Tschermak, G., 143, 159
Tufa, 43
Tuff, 4–5, 94
Tungadal River *4139*, 77, 82, 134, 138, 152–153, 199
Tuttle, O. F., 164, 171
Tyrrell, G. W., 73, 146, 159

Udairn *5142*, 9–11, 13, 75
—— Fault, 11
—— Shales, 5, 12–6, 22
Uig *3963*, 4, 8, 48, 51, 70, 127, 134–5, 163, 186, 194–5, 199, 200, 203
—— Bay *3862*, 2, 4, 70, 81, 135, 174
Ullinish *3238*, 139
—— Lodge *3237*, 158
Unconformity, 4
Upper Lava Series of Mull, 88
—— Lias, 4–5, 9–15, 19, 173, 198
—— Ollach *5136*, 199
—— '*Ostrea*' Beds, 5, 8, 18–20, 50–4, 58, 60, 68
—— Oxford Clay, 57, 62
—— Pliensbachian, 9
—— Tote *5159*, 4, 12, 16, 24, 128
Upperglen *3151*, 90

Valley glaciers, 177
Valtos *5163*, 29, 204
Variolite dykes, 134, 152–3
Varkasaig River *2341*, 185
Varragill River *4738*, 134
Vaternish, 1–3, 35–7, 42, 48, 76, 81, 87–8, 91, 95, 102, 111–2, 133–5, 137–8, 160, 182, 186, 193–4, 196, 199
—— group of lavas, 77
—— Hebridean type of lava, 87, 100–1
—— Point *2367*, 2
Vents, 139
Vesicles, 81, 93
Vesulian transgression, 17
Vidigill Burn *3936*, 133, 152
—— —— *4138*, 138–9
Vincent, E. A., 124
Voaker Burn *3539*, 137, 152, 156
Volatiles, role of, 169
Volcanic dust, 73
Von Decken, H., 7, 17
Von Oeynhausen, C., 7, 17
Von Walterstansen, 98

Wadsworth, W. J., 156, 159, 165, 171
Wager, L. R., 94, 106, 120, 123–4, 160, 164–165, 168–9, 171
Walker, F., 116, 124, 126–7, 139–43, 146–149, 159, 163, 167, 171, 196–7
Walton Naze, 187
Warboy's Pit, Huntingdonshire, 59
Washington, U.S.A., 190
Water Supply, 202
Waters, W. F., 103, 110, 119, 155
Waterstein Head *1447*, 3, 26, 36, 43, 87, 194
Watts, W. A., 80, 92
Watts, W. W., 93
Wealden, 7, 19
Weathering, late-Tertiary, 6
Wedd, C. B., iii, 6, 18–9, 48, 54–5, 176
Wells, A. K., 116, 124
Whitbian, 12, 140
White Sandstone, 5, 12–5, 18–9, 21–4, 128
Wiay *2936*, 90
Wild Bed of Chideock, 15
Wilson, A. D., 99
Wilson, G., 144
Wilson, G. V., iii, viii, 73–4, 76, 78, 94–5, 123–4, 139, 158, 171, 202
Wilson, J. S. Grant, 195, 197
Wiltshire, 61
Winchell, A. N. and H., 106, 113, 124
Wind-rounded grains, 74
Woodward, H. B., iii, 6, 9–10, 19, 55, 176
Worm casts, 32
Wright, W. B., 123, 139, 158, 171

Yeovilian, 12
Yorkshire, 12, 59, 198

Zeolites, 113–5
Zies, E. G., 202
Zirkel, F., 93
Zone, *Amaltheus margaritatus*, 9–10
—— *Amoeboceras alternans*, 69
—— *Ammonites spinatus*, 10
—— *Brasilia bradfordensis*, 16
—— *Cardioceras cawtonense*, 20, 49–50, 57–58, 60, 65, 67–8
—— —— *cordatum*, 20, 56–60, 62, 68
—— *Dactylioceras tenuicostatum*, 10–2
—— *Garantiana garantiana*, 12, 198
—— *Harpoceras falcifer*, 10–2
—— *Hildoceras bifrons*, 10
—— *Hyperlioceras discites*, 16
—— *Kosmoceras castor* and *K. pollux*, 20 57–60, 63, 68
—— —— *jason*, 20, 57–60, 62–3, 68
—— *Lioceras opalinum*, 12, 15
—— *Ludwigella concava*, 16
—— *Ludwigia murchisonae*, 12, 15–6
—— *Lytoceras jurense*, 10, 12
—— *Otoites sauzei*, 12, 16

Zone, *Paltopleuroceras spinatum*, 9–10
—— *Parkinsonia parkinsoni*, 12, 54
—— *Peltoceras atheleta*, 20, 57–60, 63, 68
—— *Perisphinctes variocostatus*, 20, 49, 57–58, 60, 64–6, 68–9
—— *Pictonia baylei*, 20, 49, 57–8, 60, 64, 66–71
—— *Pleuroceras spinatum*, 9
—— *Pleydellia aalensis*, 12
—— *Prodactylioceras davoei*, 10
Zone, *Quenstedtoceras lamberti*, 20, 57–60, 63, 68
—— —— *mariae*, 20, 57–60, 62–3, 68
—— *Ringsteadia anglica*, 20, 49, 57–8, 60, 64–71
—— *Sonninia sowerbyi*, 12, 16
—— *Stenoiceras subfurcatum*, 12, 16
—— *Stephanoceras humphriesianum*, 12, 16
—— *Tmetoceras scissum*, 15
—— *Tragophylloceras ibex*, 10

Printed in Scotland for Her Majesty's Stationery Office
by Bell and Bain Ltd., Glasgow Wt. 71197 K8

S.O. Code No. 88-7501

OXFORD POLYTECHNIC LIBRARY

OXFORD
POLYTECHNIC
LIBRARY

[illegible]

NORTHERN SKYE 80 & 90

7770747